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THE ROTATION OF JUPITER'S OUTER SATELLITES.*

WILLIAM H. PICKERING.

From what has been already stated in my former papers regarding the forms assumed by the discs of these three bodies, it will not surprise us now to learn that the phenomena presented by their rotation differ in some important particulars from those presented by the rotation of the 1st satellite. Confining our attention for the present to the 3d, the largest and most easily observed of the group, we find that the observed facts may be divided into two distinct classes, those pertaining to the form of the disc, and those pertaining to the detail exhibited by it. These classes we will discuss separately.

In a former paper it was stated that this satellite presents an elliptical phase twice during each revolution in its orbit, at an interval of thirty-four hours after passing each conjunction with the planet. When the satellite is upon the eastern side of its orbit, and presents an elliptical disc, the inclination of the major axis to the orbital plane is clearly marked. The results of twelve series of observations of the position angle of the major axis with regard to the perpendicular to this plane, taken by Mr. Douglass and myself upon seven different nights, is given in the following table. Each series is in general made up of six independent observations.

POSITION-ANGLE OF MAJOR AXIS.

Date	Obs.	P. A.	Dev.	Date	Obs.	P. A.	Dev.
Dec. 23	P	−21°.3	10°.8	Jan. 13	P	−12°.1	1°.6
"	D	−15 .2	4 .7	14	P	− 4 .1	6 .4
"	P	−12 .5	2 .0	15	P	−11 .7	1 .2
31	P	− 9 .4	1 .1	"	P	−11 .5	1 0
Jan. 1	P	− 5 .6	4 .9	29	P	− 5 .8	4 .7
"	D	− 8 .8	1 .7	"	D	− 7 .9	2 .6
					Mean	−10 .5	3 .6

* Communicated by the author.

These observations indicate a position angle of the axis of $-10°.5$. Meteorological conditions have always interfered with our observations of the elliptical phase when it occurred upon the western side of the planet. Nevertheless, it was suspected upon December 28, and distinctly seen by both Mr. Douglass and myself upon January 10 and 11. A single position-angle secured by Mr. Douglass upon January 10 between passing clouds gave the value $+5°.9$. An unsatisfactory angle taken by myself upon the evening of March 9, indicated a value of $+37°.4$. If these results are correct they would imply a revolution of the axis about the line perpendicular to the orbital plane, in about the same period as the satellite's rotation upon the axis itself. This result would appear at first sight nearly as extraordinary from a theoretical standpoint as the rotation of the satellite about its major axis,—but these points we will discuss later.

Turning now to the other class of observations upon this satellite, we find that as noted in an earlier paper, its disc presents details whose nature can without much difficulty be made out. At first it was supposed to consist of a simple band situated in the northern hemisphere of the satellite. A more careful study, however, indicates for it a somewhat more complicated structure. This marking usually appears forked, the prongs being placed at an angle varying from 30° to 60°. The fork is sometimes turned to the right and sometimes to the left, and sometimes a double fork is seen, giving the marking a shape similar to the letter X turned upon its side. Figure 4 was drawn under very favorable circumstances upon October 15^d $11^h.5$ A. M. T. Probably this drawing and two similar ones made by Mr. Douglass upon the same night give the most accurate idea of the apparent detail of any that we possess. The detail in Figure 5 is taken from a drawing made by Mr. Douglass January 29^d $8^h.7$ A. M. T. Besides the detail the drawing shows the slightly irregular shape of the elliptical disc. The first six drawings are all on a uniform scale of $\frac{1}{6000000}$ or 1 millimeter equals 250 miles. At the mean distance of the planet therefore 9 millimetres equals 1″. From a distance of nine feet the drawings will appear of the same size that the satellites do when in the telescope. The following table gives the position-angle of the axis of the northern edge of the belt referred to the axis of the orbit, upon different dates, also the deviations from the mean. The northern edge of the belt was selected since it was always the darkest and best defined region.

POSITION-ANGLE OF AXIS OF BELT.

Date	Obs.	P. A.	Dev.	Date	Obs.	P. A.	Dev.
Oct. 8	D	+ 10°	5°.5	Oct. 14	P	— 8	23°.5
"	P	+ 14	1 .5	15	P	+ 21	5 .5
"	P	+ 16	0 .5	"	D	+ 26	8 .5
"	D	+ 16	0 .5	Dec. 26	P	+ 21	5 .5
13	D	+ 11	4 .5	Jan. 1	D	+ 39	23 .5
14	P	— 1	16 .5	16	P	+ 23	7 .5
					Mean	+ 15 .5	8 .6

In all of these observations excepting those made upon October 13 and 14, the satellite occupied nearly the same place in its orbit, being between us and Jupiter, and not far from inferior conjunction. This is perhaps unfortunate, but the belt was measured at those times only when it was most readily seen, and it is apparently most conspicuous when the satellite is in this position. We therefore have no means of knowing whether its position angle changes in different portions of its orbit or not. It will be noticed that on comparing the observations of January 1 and 15, in the first table, with those of January 1 and 16, in the second, that the two axes seem to be inclined to one another on those dates between 46° and 35°, and that they are inclined upon opposite sides of the axis of the orbit. These observations were all made with a power of 700 diameters, but 1000 or 1200 would evidently have been much better had we possessed it.*

To show that the belt was a genuine phenomenon, and not an optical illusion, the following experiments were made: The eye-piece was changed and the micrometer turned. The appearance and direction of the belt remaining the same, this showed that there was no defect in the eye-piece. The telescope was turned on opposite sides of the pier, and the satellite viewed at various altitudes. This showed that there was no defect in the objective, and that there was no illusion caused by upper air currents. The observer's head was turned at different angles and both eyes were used alternately to show that there was no defect in the eye. Finally both observers worked independently. Under all circumstances the position-angle remained practically the same within the limits of error, and the belt was clearly defined.

The next question relates to the rate of rotation. Several drawings made upon the night of October 15 (the extremes being at an interval of $4^h\ 42^m$ apart), show precisely the same detail. Drawings made upon October 13 and 14 are quite similar, although in the former only the right hand, and in the latter only

* Our higher powers are not adaptable to the micrometer.

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the left hand forks are shown. In all cases the crotch of the fork is near the center of the disc, and the same remark applies to certain drawings made in 1891 in which the fork is also shown. It is possible that the crotch of the fork is an illusion caused by the "diffraction spot." Observations of another kind of detail have, however, been made, which, although too few in number to be of much service at present, yet it is thought may by sufficient repetition in the future serve as a means of settling both the direction and rate of rotation of the satellite. Upon seven nights when the satellite was between us and Jupiter a whitish spot was recorded as visible near its south pole. This spot was conspicuous, It was not brilliant like snow, but sufficiently white to attract the attention. Upon two nights when the satellite was on the further side of the planet, and shortly after passing superior conjunction, the north pole was recorded as slightly more brilliant than the south. When near eastern elongation the limb towards Jupiter was twice recorded as distinctly brighter than the other. It also appeared more sharply curved, (Figure 5.) These observations as far as they go would perhaps imply a period of rotation coinciding with that of the revolution of the satellite in its orbit.

Without attempting as yet to offer any explanation of these results, we will merely recapitulate the facts. (1st), Two observers independently see the disc of the 3d satellite flattened at regularly recurring intervals, independent of the position of the telescope, and they agree as to the direction in which the flattening occurs. This flattening has been noted by several earlier astronomers, among them Secchi, who declared that the ellipse did not always lie in the same direction. (2d), Both observers see a belt upon the satellite in the same position, in the same direction, and with the same character of detail. (3d), The observers agree that the two observations are not particularly difficult ones, requiring unusually keen eye-sight, or unusual atmospheric conditions, but are on the contrary quite evident when the attention is once called to them, and that they can be followed night after night during our clear season.

Turning now to the remaining satellites, we may remark that the detail upon them is much more difficult than that on the 3d, and requires the most favorable conditions for its detection. Of the three, that upon the 1st is probably the easiest, and consists of one or two bands lying in an approximately north and south direction, Figures 11 and 12. These drawings were made upon the nights of October 9, $12^h.0$ and upon Nov. 28, $10^h.4$ A. M. T.

The 2d satellite is undoubtedly the most difficult, and detail was detected upon only one occasion, and that is rather doubtful, Figure 3, October 15, $12^h.0$. The detail upon the 4th is very difficult considering the size of the disc. It usually appears as a broad band, but sometimes as a narrow line, in both cases it is very indistinct, Figure 6, December 29, $9^h.1$. A bright spot, shown in the figure, has several times been recorded near the north pole, and once near the south. The difficulty of observing this satellite is materially increased by its dark color. Its period and direction of rotation upon its axis have not been determined. Its disc has been recorded as shortened in the direction of the plane of its orbit upon fourteen different dates. Upon four of these it was within twenty-four hours of inferior conjunction, upon three it was equally near superior conjunction, upon three it was within twenty-four hours of eastern elongation, upon one it was equally near western elongation, and upon three it was between eastern elongation and inferior conjunction. It was recorded as circular upon eleven other nights.

Regarding the period of rotation of the 2d satellite, our recent observations confirm the period already published, although occasional discrepancies have been noted which do not seem to be due entirely to defective observations. Thus, once or twice the flattening has been but slight when it should have been quite marked, and occasionally the reverse effect has been noted. The amount of the flattening is perhaps more variable than in the case of any of the other satellites. Whether this body really suffers irregularities in the ellipticity of its disc, besides those due to its position in its orbit, must be left for future observations to determine. This question, together with others pertaining to the other satellites, will be treated more in detail and subjected to a fuller discussion elsewhere.

Before closing this series of papers it may be well to bring together all the facts so far recorded, which at first sight seem unaccountable, or were at least, unexpected, when they were first observed. They are as follows:

(*a*). The small density of all these bodies.

(*b*). The retrograde rotation of the 1st.

(*c*). The elongated shape of the 1st.

(*d*). The small density of the 1st as compared with any of the others,—from one-quarter to one-half less.

(*e*). The regularly recurring changes of shape of the discs of the outer satellites, caused apparently by a rotation about their major axes.

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(*f*). The change of position angle of the major axis of the 3d, and probably of the 4th, in different portions of their orbits.

(*g*). The considerable inclination of the axis of the belt on the 3d, both with regard to its orbit, and also to its major axis.

(*h*). The fact that in the October and November observations of the 3d satellite, it was once recorded as shortened in a polar direction, and was afterwards upon two nights recorded as "perfectly round," when it so happened as we have recently found, that it was in the position which we have designated as that of maximum ellipticity. Also that the 3d satellite has on some occasions retained its elliptical shape for a longer period than it has at others, as described in my last paper.

(*i*). That the 2d satellite was in the earlier observations frequently recorded as lengthened equatorially, whereas of late no such observation has been made, (see last paper).

(*j*). The apparent irregularities in the period and ellipticity of the 2d and perhaps of the 4th satellite.

(*k*). The occasional irregular non-elliptical shape of the disc of the 3d.

As these bodies seem to differ in so many respects from the larger and better known members of the solar system, it may be interesting to determine how completely these phenomena can be accounted for on Laplace's "ring theory" of evolution. As might be expected some modification of the theory has been found necessary, but the premises are similar and if admitted, it is believed that the conclusions necessarily follow. The premises are as follows:

(1st). Jupiter was formerly surrounded by a series of rings similar to those now surrounding Saturn.

(2d). The direction of rotation of these rings was direct like that of the planet.

(3d). By some force whose cause is not explained, they were shattered, their components uniting but still retaining the same orbit.

(4th). Like the original rings, each satellite still consists of a swarm of meteorites, their consolidation having been intercepted by the enormous tides produced in them by their primary. (See my second paper.)

Having now stated our premises, and described the facts for which our hypothesis must account, we will point out that fact (*a*) is explained by the 4th premise. If the rings had been solid bodies each moving as one piece, it is evident that their outer edges would have moved faster than their inner ones, and had

they later been shattered by some cause, and converted into one or more separate satellites, that each satellite would have had a direct rotation like the ring from which it was formed. If, however, the rings were composed of meteorites, as has been shown is necessarily the case with the ring of Saturn their inner edges would travel the faster, and upon their breaking up, the resultant satellites would all have a retrograde rotation, fact (*b*).

When the satellites were formed from the rings, the transformation would not be instantaneous. Presumably several centers of condensation would be formed, which would later unite. Even upon the gradual collision and agglomeration of these masses the spherical form would not at once be assumed, but would only occur after all free translation of the particles among themselves had ceased, fact (*c*). While such relative motion of the particles was maintained, the apparent density of the mass would be less than after it had ceased, and assumed a spherical form. The 1st satellite departs most from the spherical form, fact (*d*).

Dealing with this matter for the moment from the quantitative standpoint, it may be shown that if Jupiter was formerly surrounded by a ring one quarter of a mile in thickness, nine thousand miles in breadth, of the same density as the 1st satellite, and coinciding with its orbit, that on being broken up, if the parts later united to form a satellite, the resultant body would have the same mass, the same size, and the same rate of rotation that we actually find at present. If in the ring form, the meteorites were six or seven times as far apart as we now find them in the satellite, the thickness of the ring would be increased to from fifty to one hundred miles. It is possible that a subsequent gravitational condensation might have influenced the destruction of the ring. Comparing this supposed ring with the outer one of Saturn, we find it would have had three times the diameter. Saturn's ring is ten thousand miles in breadth. Its thickness is unknown, but it has been variously estimated at from forty to one hundred and forty miles.

As any satellite composed of particles free to move among themselves revolves about its primary, there will be a tendency to form tides within it elongating the satellites in the direction of the radius vector. Owing to the rotation of the satellite, the elongation will really make a certain angle with this line. The attraction of the primary acting upon these protuberant regions tends to give the satellite a rotation, the same in direction and period as that of its revolution in its orbit. But a satellite revolving in a retrograde direction is under these circumstances in

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a position of unstable equilibrium, and the slightest disturbance of its plane of rotation will cause it under this tidal retardation to change its plane with increasing velocity, until it is placed at right angles to the plane of its orbit. After that the change will continue with diminishing intensity until a direct rotation is established coincident with the plane of the orbit. It will be noted that this disturbing force acts at right angles to that producing the precession of the equinoxes. Those who desire a visible illustration of this change of plane can readily obtain it with an ordinary gyroscope. If through condensation, the tides cease before this result is attained, the satellite will continue to rotate in a plane more or less inclined to that of its orbit. The periodically flattened appearance of Jupiter's outer satellites, however, is not due to the tides, which although theoretically some miles in height, could not be seen from the Earth. What applies to the larger planets is upon this theory true also of the smaller ones, including the Earth, which must formerly have revolved in a retrograde direction. Accordingly terrestrial objects now situated to the south of us would then have been found under the northern stars, the Sun itself rising in the west and setting in the east, while the stars moved backwards in their nightly courses. As the plane of rotation changed, the Earth's axis approached, and finally coincided with the plane of its orbit. The Sun then spiralled around the Earth from pole to pole every six months, the tropics reaching the poles, and the polar circles the equator. At present the Earth's equator coincides more nearly with its orbit than does that of Mars, thus further illustrating the same law that applies to the outer planets. Turning now to the Solar System, we find that the inclination of the planes of rotation of the outer satellite systems (145°, 98°, 28°, 2°), and presumably of the outer planets themselves, are arranged in a continuous series, the outer planet, having changed least from its original retrograde rotation. This might imply that the outer planet was formed last, but judging from the analogy of the satellite systems of Jupiter and Saturn, we should rather attribute it to the weakness of the solar tides produced upon a smaller body at that enormous distance.

It has been argued that if such rings once extended around the Sun, similar rings must still be in existence in other parts of the sidereal universe and from their enormous extent should be visible from the Earth, at least as discs, if nothing more. Such rings, however, on account of their vast surface, in proportion to their mass, must almost necessarily be cold bodies, illuminated

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at a very small angle by their central Sun. We should not then expect that they would be visible, until through some catastrophe they condensed to form a companion Sun. Thus formed they would quite probably be composed of lighter material than the central body, and from this fact, taken in connection with their more recent formation, we should naturally expect that they would present to us a somewhat different spectrum.

Returning from this digression to the satellite system, let us consider the case of a satellite whose plane of rotation had been changed by the tides to a direct motion, but slightly inclined to the plane of its orbit. Let Figure 8 represent such a body. In such a case all of the component meteorites revolve in circular orbits in parallel planes perpendicular to the axis. But owing to this inclination and to the varying attractions of the other satellites, it will be impossible for these orbits to retain their circular form. They will accordingly become slightly elliptical. In so doing, however, their apaxons or the portions of their orbits most distant from the axis will not all be found upon the same side. The swarm must still be symmetrical about its center of gravity. Accordingly for each apaxon found to the right of the axis in the northern hemisphere, there will be a corresponding one found to the left of the axis in the southern. The equatorial plane will then still be circular, and the ellipticity of the orbits will increase steadily as we approach the poles, (Figure 7). Apparently this form necessarily follows upon any distortion of the circular orbits. The perturbation of these elliptical orbits by Jupiter will cause a rapid rotation of the apsides. When these point towards the Earth, the satellite will present a circular disc, (Figure 8). When they have changed their position by 180° they will present the appearance shown in Figure 9, which is similar to that shown in Figure 7, but with a changed position angle. Now these are precisely the changes of shape referred to under facts *e*, *f*, and *g*. Moreover, our micrometer measurements of the 3d satellite show that the diameter when the circular phase is presented is intermediate in length between the two axes when the satellite presents an elliptical disc. The true shape of the satellite is therefore an ellipsoid of three unequal axes.

When the major axis is most inclined to the plane of the orbit, as in Figure 9, the action of Jupiter is to draw the north pole inwards. Although the plane in which this force acts varies in different portions of the orbit, yet the same absolute direction is maintained on the whole, with the result that a precession of the equinoxes is established. But the interesting feature of this pre-

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cession is that it will take place in the opposite direction to that in which it occurs in the better known members of the solar system, that is to say the rotation will be direct. As a result of this rotation, we shall find that the elliptical phase is not always shown at the same interval after passing conjunction, and that the position-angle of the major axis of the ellipse will vary. If the axis of the satellite, instead of lying in a plane perpendicular to the line of sight, were inclined directly towards, or from us, we should have the series of appearances presented in Figures 10, 11 and 12. That these appearances were presented with more or less distinctness in the cases of the 2d and 3d satellites, in the months of October and November is indicated under facts *h*, *i* and *j*. That such a rotation took place in the case of the 3d satellite is further indicated by our drawings of the belt. In those drawings made early in October, the belt is placed further north than in any made since that time. Moreover, in these earlier showings the belt is concave towards the south, while in the later drawings the concavity is towards the north, and the belt itself is further south. Compare Figures 4 and 5 with Figures 8 and 10. The period of this rotation is unknown, but an examination of our drawings leads me to suspect that it may prove to be about ten weeks. We have no evidence as to its direction, but venture to predict as a test of our theory, that future observations will show it to be direct.

There is one objection which might be raised to this theory, and which therefore requires further elucidation. The precession of the equinoxes, or revolution of the nodes of the orbits of the meteorites, if we prefer that term, requires in the case of the 3d satellite, as we have seen, a period of at least several weeks. The revolution of the apsides of their orbits, on the other hand, is accomplished in a single revolution of the satellite about Jupiter. In the cases of the 2d and 4th satellites, the revolution of the apsides is proportionately still more rapid. If this revolution were caused merely by the perturbations induced by Jupiter itself, the period would necessarily be greater than one revolution of the satellite in its orbit. Probably the most prominent fact bearing upon this question pertains to the density of these bodies. Their density—although small compared to that of most of the members of the solar system, is still so great that we can be pretty certain that the volume of the free space surrounding each meteor does not on the average much exceed ten times the bulk of the meteor itself. This would imply for the meteors a specific gravity of between ten and twenty times that of water. Accordingly

they must be in a constant state of collision, and a considerable amount of heat must thus be produced, and lost to the system. This would imply a reduction in the rate of rotation of the satellite as a whole, were it not for the tidal forces engendered by the proximity of their primary. These forces as we have already remarked would also tend to reduce the rate of rotation, until it coincided with that of the revolution of the satellite in its orbit; after this rate was reached, the tides would tend to maintain it. The facts of observation, as far as they go, seem to show that this is the present condition of the 3d satellite. As a consequence, the meteorites although arranged in elliptical orbits, really describe circular paths around their common axis of rotation. Under these circumstances there is less friction among the meteorites themselves, since each would maintain a uniform velocity, than if they actually moved each in an elliptical path. This may therefore be considered as a condition of stable equilibrium which once established would be permanent. The same argument which applies to the rotation of the apsides of the meteorites composing the 3d satellite, applies equally to the cases of the 1st, 2d, and 4th. The period of revolution of the meteorites in their orbits about the axis of the satellite, in each case coincides with the period of revolution of the apsides of these orbits, and consequently each meteorite describes a circular path about the central axis.

There is a peculiarity pertaining to the third satellite which must now be explained—the occasional irregular shape of its disc. Let Figure 7 represent the position of the axes of the satellite when near eastern elongation, then Figure 8 will represent the appearance of the two conjunctions, and Figure 9 that of western elongation. An examination of these figures will show that although the southern hemisphere is in one part of the orbit nearer to Jupiter than the northern, that on the whole the northern is nearer, and is therefore more attracted by the planet. This condition of affairs will continue until by the precession of the nodes the axis of the satellite is turned the other way. As a result, we should expect that during half the period of precession the northern hemisphere of the satellite would be drawn rather nearer the planet than its mean position, and that during the remainder of the time the other hemisphere would be similarly distorted (fact *k*). Figure 5 shows the distortion of the disc of the 3rd satellite as it appeared to me upon January 29, and also upon December 31, when the satellite was also near eastern elongation. Since the apsides of both the 2d and 4th satellites complete ap-

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proximately two revolutions during one revolution of the satellites in their orbits, in their cases no such distortion should occur. None has hitherto been recorded.

All of the observed facts have now been accounted for, aud I have endeavored to show, not only that we may thus explain all the facts observed, but also, admitting the premises, that at some time in the history of the system, all of the more important of these phenomena must necessarily have presented themselves. In this paper I have made no attempt to treat the matter from a mathematical standpoint. Such an attempt would indeed be quite useless, with the very insufficient data at present at our disposal. As stated in a former paper, this lack is in part due to my absence from the Observatory, and in part to the pressure of routine work. It is also very largely due, especially as regards the three outer satellites, to the fact that at the time our observations were made, we had not the slightest comprehension of the nature of the phenomena that were presented to our view. The facts were collected as they were observed, and recorded, without any theory whatever to guide us, and many valuable opportunities were thus undoubtedly lost, merely from the fact that we did not know what phenomena to expect, or to what points we could most profitably direct our attention. This year's observations have, however, put us in possession of a theory, and it is hoped that the observations of another year may supply at least a portion of the requisite numerical data. As I am about to return to Cambridge temporarily, where the climate is such, that this class of observation is entirely out of the question, I have collected together the following notes, hoping that they may be of assistance to those astronomically more favorably situated. They consist merely of a series of suggestions regarding the points to which the attention can be most profitably directed in the case of each satellite, together with a letter intended to indicate the difficulty of the observation. Thus, those observers, who are located under such climatic conditions that they cannot profitably employ a magnification greater than 400 diameters, may devote their attention to the observations marked "*a*," but it would be a waste of time for them to attempt any of the others. Those observers who can employ 700 diameters may attempt those observations marked both "*b*" and "*c*," but they will find the latter difficult, and for these can most profitably employ a power of 1000 diameters. I have classified these observations by the magnifying power, rather than by the aperture of the telescope, because as we have shown, they can be repeated by any

one possessing a telescope of 13 inches aperture, under favorable atmospheric conditions, whereas the largest aperture would be useless were the climate unfavorable. When the small letter is in italic, the observation should be made, if possible, whenever the satellite is observed.

1ST SATELLITE.

a. Color as compared with 2d and 3d. This has been thought to vary. It can be studied best when near one of these bodies, but only when the sky is perfectly clear from haze.

a. Position angle of the major axes when near maximum ellipticity.

b. Ratio of major and minor axes, both by micrometer and estimation, when at maximum ellipticity. The ellipticity of Jupiter makes an excellent standard for purposes of estimation, and may be called 5, a circular phase being indicated by 0.

b. Determination of period by observation of circular phase.

c. Shape of disc when of minimum phase.

c. Distortion of disc from elliptical shape. I have never been able to see this phenomenon myself, although it has been recorded once or twice by Mr. Douglass.

c. Study of detail by means of drawings.

2D SATELLITE.

a. Color as compared with 1st and 3d.

b. Ratio, probably best by estimation, of the major and minor axes of the disc.

b. When occulted with phase near maximum ellipticity, note change of position-angle of axes, caused by the refraction of Jupiter's atmosphere.

c. Position-angle of major axis at times of maximum ellipticity.

c. Study of detail,—very difficult.

3D SATELLITE.

a. Determination of the refraction of Jupiter's atmosphere when this satellite is occulted by the dark limb. See my third paper. Before opposition the second and fourth contacts can be observed after opposition the first and third.

a. Color as compared with 1st and 2d satellites.

a. Position-angle of major axis.

a. Ratio of major and minor axis by micrometer, and also by estimation.

a. Drawings of detail. Study of rotation by observation of bright polar spots, and varying relative brightness of limbs.

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b. Distortion of disc from the elliptical shape. Precise nature and position-angle of the distortion.

b. Position-angle of belt.

c. Estimation of location of belt between the northern and southern poles of its axis. Direction of its curvature.

4TH SATELLITE.

a. Color as compared with the brightest parts of Jupiter taken as a standard of white. This can only be satisfactorily observed when near the planet.

b. Ratio of major and minor axes. This can probably be best obtained by estimation, but the micrometer might be tried.

b. Study of rotation by observations of the bright polar spots.

c. Position-angle of the major axis.

c. Study of surface as to detail, and also as to relative color of different regions.

c. Distortion of disc from elliptical shape, when at maximum ellipticity. This has never been noticed here, but it is desirable to settle the question of its non-existence.

In the above list of suggestions, I have included under each satellite only those observations which our experience here has led me to think it is practicable to make. With the exception noted, each of these observations has been made in Arequipa this past year.

AREQUIPA, Peru, March 20, 1893.

THE ORBIT OF 9 ARGUS. (*β* 101).*

S. W. BURNHAM.

This close pair was discovered with the 6-inch refractor in 1873. The attention of Baron Dembowski was called to it, and in 1875 it was measured by that distinguished observer. It was evident in the course of a very few years that it was a binary in rapid movement. Since that time the angular motion has been nearly 180°. For some years it has been a difficult pair to measure, and at the time of my last observations in 1892, it was a hard star with the 36-inch.

Last year Professor Glasenapp computed the orbit of this pair (*Monthly Notices*, June 1892) using my last measures at Mt. Hamilton, and found a period of 40.54 years. This orbit repres-

* Communicated by the author.

ented all the measures very satisfactorily with the single exception of the distance in the last measures of 1892. I found the distance to be 0″.22, and the orbit required that the distance at this time should be 0″.38. The largest error in the other observed distances was only 0″.07. The measures of 1889-91 did not show any diminution in the distance, and it would be very natural for any one but the observer to assume that the measured distance in 1892 was too small, and that it should be made to conform to the previous observations. But having made these measures on three different nights, and having looked at the star on several other occasions when it was too difficult with the then conditions to be well measured, I am able to say with confidence that my distance is substantially correct, and certainly not sensibly too large. One could not possibly make an error of 0″.16 in estimating, without the use of the micrometer at all, a distance of 0″.22. The error of estimation in such a pair ought not to much exceed 0″.05 where the observer has had considerable experience in this kind of work. I feel confident that at this time the distance of the components was not greater than 0″.25.

If this is the fact, it is obvious that Glasenapp's ellipse is incorrect, notwithstanding it represents all the other measures very perfectly, and that his period is much too long.

He has used the following measures:

Date	P	D	*n*	
1875.71	289°.4	0″.46	3	*Δ*
78.50	302 .2	0 .45	4	Cin—*β*
79.68	306 .2	0 .38	2	Hl
82.21	319 .7	0 .35	4	Sp
83.11	336 .2	0 .30	1	*β*
89 08	76 .4	0 .34	4	*β*
90.22	83 .8	0 .34	6	*β*—Sp
91.06	91 .5	0 .34	4	*β*—Sp
92.05	98 .7	0 .22	3	*β*

Glasenapp's orbit is shown by the large ellipse on the accompanying diagram, and the nine observed positions given above are accurately laid down to scale. It will be seen that this ellipse represents all the measures except the last, where the measured distance appears to be altogether wrong. As I have already said, I have every confidence in the substantial accuracy of this result, as well from the appearance of the star, which is perfectly remembered at this time, as from the micrometrical measures themselves. I have therefore, endeavored to ascertain whether some other ellipse could not be found which would repesent the measures of 1891 equally as well as those made previous to that time. There was no difficulty in describing an ellipse which represented

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quite as well as the other all the observations down to 1891, and at the same time made the last distance in 1892 entirely satisfactory. As this ellipse was finally rejected, it is not shown on the diagram. The following are the corrections which must be applied to the actual measures to make them conform to the respective apparent orbits:

	G		*β*	
1875.71	−1°.9	−0.03	0°.0	+0″.01
78.50	−1 .1	−0.03	−1 .0	0 .00
79.68	+1 .2	+0.02	+0 .9	+0 .02
82.21	+5 .2	−0.03	+6 .8	−0 .05
83.11	−2 .5	−0.01	0 .0	−0 .03
89.08	−2 .8	−0.07	−3 .5	−0 .01
90.22	+1 .6	−0.02	−2 .0	−0 .02
91.06	+0 .6	+0 01	−2 .5	0 .00
92.05	0 .0	+0.16	0 .0	+0 .03

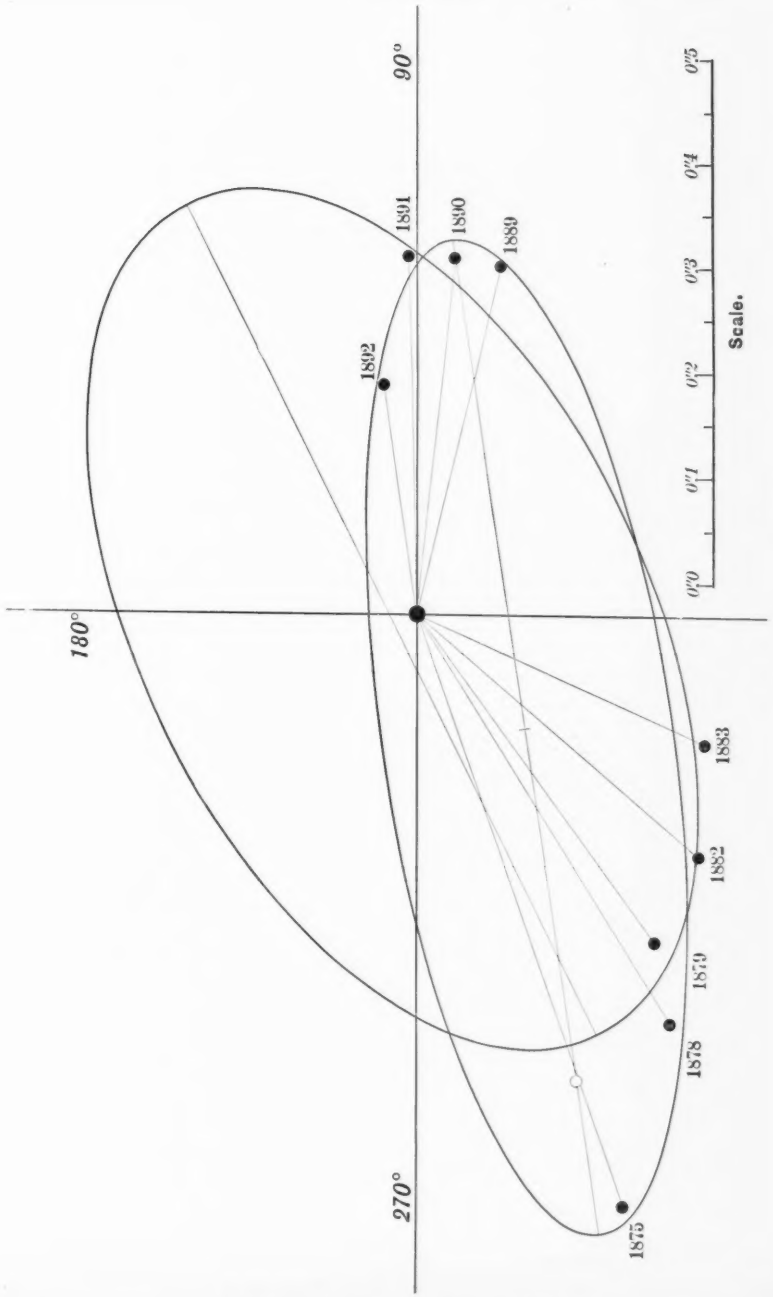
It will be observed that these ellipses are entirely different, and have in fact, nothing in common. But one orbit is known of a binary system where the eccentricity is so small as that of the larger of these ellipses, while in the other the eccentricity is one of the largest known. The following elements are derived from the apparent orbits:

	G	*β*
P =	40.54 years	20.0 years.
T =	1844.02	1892.8
e =	0.09	0.72

If the first is correct, this should now be a very easy pair, as the distance would be between 0″.4 and 0″.5; on the other hand in the other ellipse the distance at this time would be so small, that the star would be apparently single in nearly every telescope in the world. I have examined this pair twice with the 18½-inch refractor of the Dearborn Observatory within the last few weeks. The seeing was not very good on either occasion, and perhaps an exceedingly close pair would not have been seen. No certain elongation could de detected with any power, and there seemed to be no doubt of its being very close or practically single with ordinary instruments.

Certainly one would be justified in assuming from the agreement of the theory with the observations, that there was hardly any question that the smaller ellipse was very near the truth, and that nothing better could be done with the present data. But when we come to examine the question in another way, we see at once that notwithstanding this beautiful agreement, the result is impossible, and that the assumed premises must be somewhere fatally defective. This pair was discovered on March 11, 1873, and, therefore, with a period of 20 years it should have completed

PLATE XXVII.



9 Argus. β 101.

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one revolution at the date 1893.19, while as a matter of fact at the beginning of 1892 the companion was still about 180° from the place where it was first seen. The angular motion in this part of the orbit would necessarily be very rapid, but the period must exceed twenty years, as otherwise at this time the companion would be in the fourth quadrant, and it would be readily seen with instruments as small as that with which it was discovered. I have given the result of this investigation, because it is a good illustration of how unsafe it is to rely upon a favoroble showing of this character, without some other independent evidence. Many astronomical castles in the air have been reared upon beautiful and elaborate columns of residuals which appeared for the time to be without defect or weakness.

While this ellipse is satisfactory so far as the observations which have been used are concerned, evidently some important consideration has been over-looked which should have entered into the calculation. Referring to my *Second Catalogue of New Double Stars* (*Monthly Notices*, May, 1873) where this pair was first published, it will be seen that the estimated distance is given 0″.7, and the angle 120° (300°), the components being considered of equal magnitude. I have not been able to consult my original observing book of that date, but I find in the *Astronomical Register* for June 1873 an article on this star written by me in which it is stated, "the distance I estimate from 0″.5 to 0″.7." I think it is safe to assume that the probable error of the estimate would place the star not far from this mean. In this connection I may mention that in a later number of the same journal (*Ast. Reg.* Feb. 1876) I gave the result of a comparison of all my estimates of the distances of double stars discovered by me down to that time, with the subsequent measures of Dembowski, and from this it appeared that in estimating the distance of pairs where it did not exceed 1″, and of course many of them would be less than 0″.5, the mean error was 0″.11. Therefore I think we may say that the real distance of 9 Argus at the time of discovery was about 0″.6.

For the purpose of getting all the information possible concerning the relative position of the components in the early part of the observed revolution, it is desirable to examine criticaliy the first measures that were made. We find the following individual measures by Dembowski, with the mean result which he adopted:

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1875.244	289°.6	Cuneata
75.249	289 .9	0″.58
76.071	(314 .0)	0 .35 al piu
76.263	288 .8	0 .44 cuneo
1875.71	289°.4	0″.46

This mean is used by Glasenapp in his orbit, and by me in drawing the twenty year ellipse. Now, it is clear that in a rapidly moving pair like this, observations in different years should not be combined unless for exceptional reasons, and that the two positions in 1875 should stand by themselves. From all the evidence it would seem that the measured distance of 0″.58 was probably about right, and I have therefore adopted the mean of these two measures:

$$1875.24 \qquad P = 289°.7 \qquad D = 0''.58$$

The angles in 1876 differ so much that no use can be made of them. A mean cannot be used where the discrepancy is so large, and the only safe way is to reject them altogether.

We have now additional data for a new apparant orbit which will necessarily be wholly unlike the large ellipse, and in some respects will differ from the other. The new position from Dembowski's measures in 1875, given above, is laid down on the diagram, and all of the measures used are represented by dark circles. The position from the mean of all Dembowski's observations, which is now rejected, is shown by the white circle.

The ellipse shown on the diagram was then carefully drawn to represent in the best possible way all of these observed positions, and make the areas proportional to the times. How successfully this has been done will be seen from the following corrections which have to be applied to the observations to make them conform to this orbit:

1875.24	0°.0	+ 0″.01
78.50	− 1 .7	+ 0 .04
79.68	− 0 .5	+ 0 .05
82.21	+ 5 .0	− 0 .04
83.11	0 .0	− 0 .04
89.08	− 3 .8	− 0 .01
90.22	− 1 .8	+ 0 .02
91.06	− 2 .7	0 .00
92.05	0 .0	+ 0 .02

From this ellipse we get directly the following elements:

$$P = 23.3 \text{ years.}$$
$$T = 1892.7$$
$$e = 0.68$$

According to this orbit, the position-angle at the time of discovery (1873.19) was 283°.5, and the distance 0″.58. This agrees well with my estimates at that time, and all the subsequent measures, including the last observations at Mt. Hamilton, are satisfactorily represented.

We have not long to wait to determine whether or not this orbit is generally accurate. The enormous angular velocity from the date of the last measures, should in the two years following that time, carry the companion over an arc of about 180°, so that when this pair can be observed again at the beginning of 1894, the position-angle should be a little more than 270°, and the distance about 0″.35. This will make it easily measurable with ordinary telescopes, and it can then be determined at once what, if any, corrections are necessary in this ellipse.

CHICAGO, April 27.

NOTE.—Since the foregoing was written and forwarded to the editor, I have shown the original diagram to my friend, Dr. T. J. J. See of the University of Chicago, and he has kindly computed from this apparent ellipse the elements of the real orbit by the method of Klinkerfues. Dr. See finds from the ellipse shown on the diagram the following:

ELEMENTS OF 9 ARGUS. β 101.

$$
\begin{aligned}
P &= 23.377 \text{ years} \\
T &= 1892.706 \\
e &= 0.68 \\
i &= 76°.87 \\
\omega &= 95\ .75 \\
\pi - \omega &= 73\ .92 \\
a &= 0''.612 \\
n &= +\ 15.3998
\end{aligned}
$$

It will be seen that the elements previously obtained directly from the diagram are practically identical, as far as they go, with those deduced by the more rigorous method used by Dr. See.

ORBIT OF A NEW RAPID BINARY STAR 20 PERSEI = β 524.*

MY DEAR SIR:

As soon as I received your letter with the observations of 20 Persei ($\alpha = 2^h\ 47^m.4$, $\delta = +\ 37°\ 56'$: 1900) I determined the elements of the true orbit. Here are the observations of 20 Persei, which you have had the kindness to send to me:

* A letter from Professor S. Glasenapp to S. W. Burnham.

t	ϑ	ρ	Observer	Number of nights.
1878.72	156°.0	0″.25	β	4n
80.53	141 .4	0 .22	β	3n
89.59	291 .3	0 .17	β	1n
90.61	287 .6	0 .18	β	3n
91.79	281 .7	0 .15	β	3n

From your drawing I have obtained the following geometrical elements:

$$\begin{aligned} \varphi &= 133°.03 \\ \lambda &= 263\ .70 \\ i &= 73\ .62 \\ e &= 0\ .478 \quad (\varphi = 28°.55) \\ a &= 0″.25 \end{aligned}$$

The dynamical elements T and U were evaluated from the two first observations and the last one by means of the following formula:

$$T = \frac{t' + t}{2} - \frac{M' + M}{M' - M} \cdot \frac{t' - t}{2}$$

$$n = \frac{M' - M}{t' - t}\ ;\ U = \frac{360°}{n}$$

where M and t represent the mean anomaly and the time for the mean of the first two observations, and M′, t' — the same quantities for the last observation. Thus, we obtained:

$$\begin{aligned} T_0 &= 1885.22 \\ U_0 &= 21.75 \text{ years.} \\ n_0 &= -16°.547 \end{aligned}$$

To find the corrections of the dynamical elements from all observations, I have proceeded in the following way:

Let T_0 and n_0 be the approximate values of the periastron passage, and of the mean motion; dT_0 and dn_0 — their corrections; T and n — the most probable values of the periastron passage and of the mean motion. Then we have:

$$\begin{aligned} T &= T_0 + dT_0 \\ n &= n_0 + dn_0 \end{aligned} \qquad (A)$$

If the geometrical elements obtained were considered as perfectly exact, and if the measures were also absolutely correct, the well known equation:

$$E - e \sin E = n(t - T) \qquad (B)$$

would be exactly satisfied. But we know only approximate values of T and n, and the measures always contain errors; therefore this equation will be not generally exactly satisfied. The difference between $E - e \sin E$ and $n(t - T)$ may be considered as a

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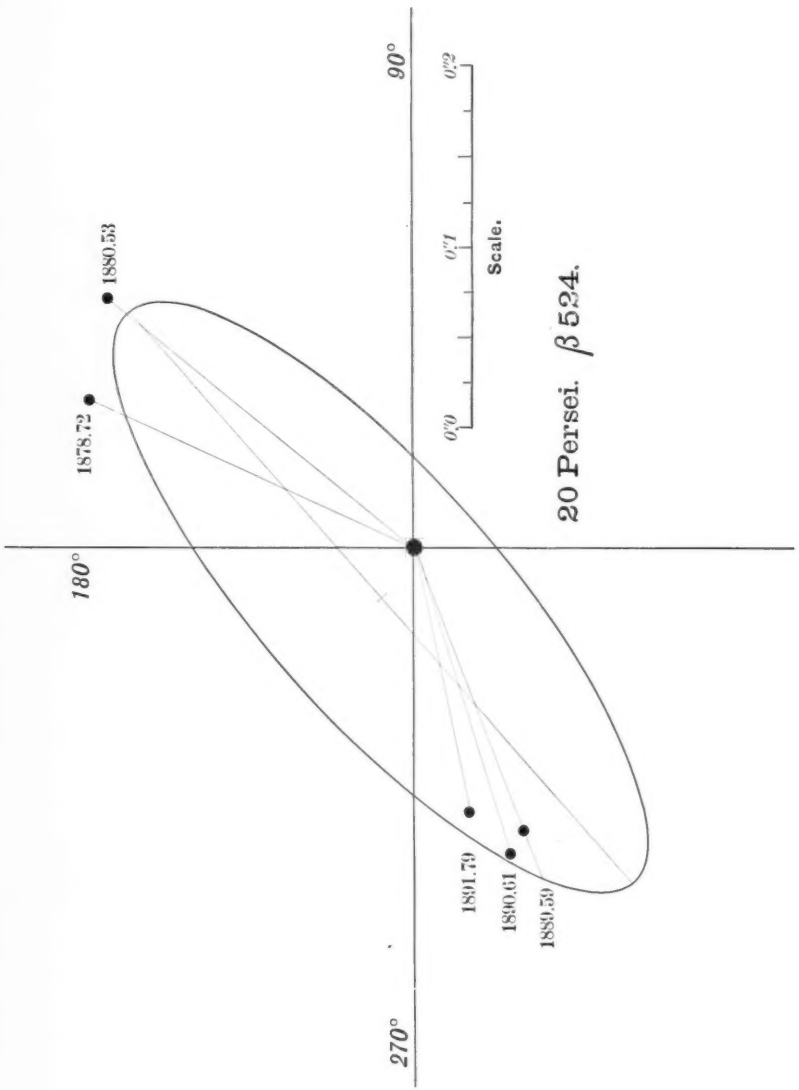
PLATE XXVII a.



function of the unknown corrections of the elements and of the occasional errors of observation.

If we introduce in the last equation the values of T and n from the above relations (A), we will have

$$E - e \sin E = (n_0 + dn_0)\,[t - (T_0 + dT_0)]$$

or:

$$-(n_0 + dn_0)dT_0 + (t - T_0)dn_0 + n(t - T_0) - (E - e \sin E) = 0$$

If we put for brevity:

$$Z = -(n_0 + dn_0)dT_0$$
$$w = n_0(t - T_0) - (E - e \sin E)$$

we will have

$$Z + (t - T_0)\,dn_0 + w = 0 \qquad (C)$$

The excentric anomaly must be calculated with the given elements and the observed θ by the formula:

$$\operatorname{tang}(v + \lambda) = \operatorname{tang}(\theta - \Omega)\sec i$$

$$\operatorname{tang}\frac{E}{2} = \operatorname{tang}\left(45^\circ - \frac{\varphi}{2}\right)\operatorname{tang}\frac{v}{2}$$

$$e = \sin \varphi$$

The values of $t - T_0$ and w are to be found in the next table:

t	$t - T$	η_0	$E - e \sin E$	$n_0(t - T_0)$	w
1878.72	− 6.24	156°.0	116°.29	107°.55	− 8°.74
80.53	− 4.43	141 .4	68 .97	77 .61	+ 8 .64
89.59	+4.63	291 .3	269 .99	287 .69	+17 .70
90.61	+5.65	287 .6	262 .11	270 .81	+ 8 .70
91.79	+6.83	281 .7	251 .33	251 .28	− 0 .05

From these data we obtain the following equations of condition (C):

$$1 - 6.24\,dn_0 - 8.74 = 0$$
$$1 - 4.43\,dn_0 + 8.64 = 0$$
$$1 + 4.63\,dn_0 + 17.70 = 0$$
$$1 + 5.65\,dn_0 + 8.70 = 0$$
$$1 + 6.83\,dn_0 - 0.05 = 0$$

The solution of these equations by the method of least squares gives us the following normal equations:

$$5Z + 5.14dn_0 + 26.25 = 0$$
$$+ 5.14\,Z + 155.57dn_0 + 144.73 = 0$$

from which we obtain:

$$Z = -4.45$$
$$dn_0 = -0°.783$$

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and finally:

$$n = n_0 + dn_0 = -17°.330$$

$$dT = \frac{+4.45}{-17.330} = -0.26 \text{ years.}$$

Hence, the dynamical elements obtain the following values:

$$T = 1885.22 - 0.26 = 1884.96$$

$$n = -17°.330;\ U = 20.77 \text{ years}$$

and the system of elements of the true orbit of 20 Persei:

$T = 1884.96$
$U = 20.77$ years
$n = -17°.330$
$\Omega = 133.03$
$\lambda = 263.70$
$i = 73.62$
$e = 0.478 \quad (\varphi = 28° 55)$
$a = 0''.25$

We give here the comparison of these elements with the observations:

t	ϑ_o	ϑ_c	$\vartheta_o - \vartheta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$
1878.72	156°.0	153°.0	+ 3°.0	0''.25	0''.21	+ 0''.04
80.53	141 .4	143 .5	− 2 .1	0 .22	0 .24	− 0 .02
89.59	291 .3	295 .4	− 4 .1	0 .17	0 .20	− 0 .03
90.61	287 .6	287 .6	0 .0	0 .18	0 .18	0
91.79	281 .7	275 .3	+ 6 .4	0 .15	0 .15	0

From a simple inspection of the residuals it seems that the signs of the residuals $\theta_o - \theta_c$ recur about as might be expected when the elements are inexact; but as the last three observations lie very near to each other, we must consider the residuals and their signs having an accidental character.

The number of observations is too small to obtain corrections of the elements. It is better to wait for new observations which can be made with large telescopes after the next two or three years.

An ephemeris of the satellite of 20 Persei is given in the next table:

Ephemeris of Persei = β 524.

t	ϑ	ρ
1893.83	238°	0''.106
1894.83	214	0 .105
1895.83	192	0 .120
1896.83	176	0 .144
1897.83	165	0 .169
1898.83	157	0 .197
1899.83	151	0 .219
1900.83	146	0 .233
1901.83	141	0 .235
1902.83	136	0 .220

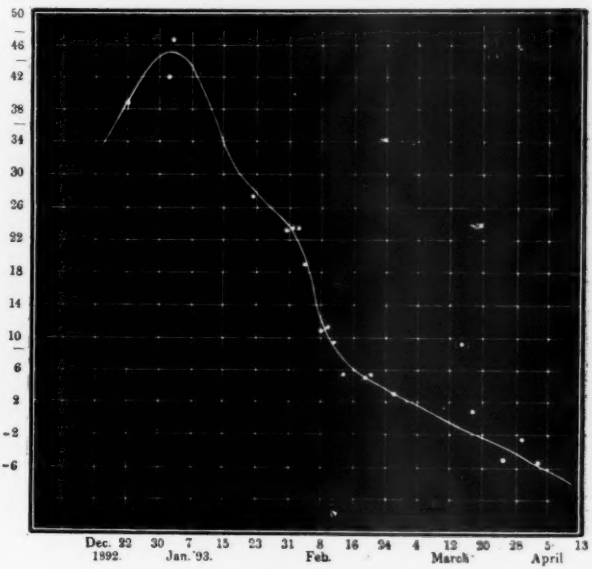
Professor S. GLASENAPP.
OBSERVATORY Georgiewskaja Abastuman.

THE NEW VARIABLE STAR IN ARIES.*

PROFESSOR S. GLASENAPP.

In ASTTRONOMY AND ASTRO-PHYSICS for October, 1892, p. 251, is printed a sketch of the stars surrounding the new variable star in Aries which I believe may be called U Arietis. From December 22, 1892, to April 2, 1893, I have observed this star on 21 nights, and have obtained a well marked maximum on January 1, 1893. Four stars were selected for comparison; their positions were estimated from the above mentioned sketch as follows:

a:	$\alpha = 3^h\ 5.0^m$	$\delta = +14^\circ\ 15'$
b:	$\alpha = 3\ \ 5\ 2$	$\delta = +14\ \ \ 7$
d:	$\alpha = 3\ \ 4.6$	$\delta = +14\ \ 27$
f:	$\alpha = 3\ \ 4.6$	$\delta = +14\ \ 26.8$



Variation in brightness of U Arietis.

The two stars *a* and *b* may be found in the Argelander's Bonner Durchmusterung, namely:

a = BD. 14° 527	$\alpha = 3^h\ 3^m\ 4\ 7$	$\delta = +14^\circ\ 8.7'$	(9.5^m)	for 1855.0
b = BD. 14 529	$\alpha = 3\ \ 3\ 20.3$	$\delta = +14\ \ 1.7$	$(9.5\ \ )$	

* Communicated by the author.

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From the observations made at Abastuman I have deduced the following scale of brightness of the comparison stars by Argelander's method "Hufenschätzungen":

$a = 36.9$ "Stufe" or degrees.
$b = 33.0$ " "
$d = 6.1$ " "
$f = 0.0$ " "

Between b and d there are no suitable stars for comparison in the field of the 9-inch refractor; therefore I was obliged to content myself with the large difference of light between these two stars. I had it in view to take a fifth star for comparison and selected the following:

c: $\alpha = 3^h\ 4.8^m$ $\delta = +14°\ 43'$

but it is a double star, which might make the comparison uncertain; and for this reason it was omitted.

The star f, which lies very near to d and follows it, is a very faint star.

The variable U Arietis is determined by the following co-ordinates:

$\alpha = 3^h\ 4.9^m$ $\delta = +14°\ 24'$

The following is a copy of the observations:

Date.	Mean time of Abastuman. h	m	Observations.	$D_\odot$
1882. Dec. 22	11	15	U 6a; U 12b; U is read.	39.0
1893. Jan. 1	7	0	U 9a; U 15b; U is read.	42.0
2	9	46	U 15a; U 20b.	47.5
22	7	30	a7 U; U 1b	27.0
30	8	27	a10 U; b 4 U.	23.0
Feb. 1	7	27	a9 U; b 4 U.	23.5
2	8	39	a10 U; b 3 U.	22.5
4	8	50	a15 U; b 7 U.	19.0
8	7	45	a > U; b 12 U.	11.0
9	9	6	a25 U; b 10 U; U 2d.	11.2
10	8	52	a25-30 U; b 12 U; d2 U.	9.7
13	7	3	a30 U; b 15 U; d3 U; U 5f.	5.9
19	7	10	a35 U; b 17 U; U d; U 6f.	5.1
20	7	20	a35 U; b 20 U; U 1d; U 9f.	5.4
26	7	25	d4 U; moonshine; thin clouds.	2.7
Mch. 15	6	47	a25-30 U; clouds, inexact.	(9.4)
17	7	20	d5 U; U f; good observation.	0.8
18	7	30	U is visible, but clouds do not permit to make a valuable estimation.	
25	8	10	d and f are visible, U is not visible; full moon; I suppose that U can not be brighter than U = f − 5.	− 5.0
39	7	40	f2 − 3 U; strong moonlight.	− 2.5
April 2	7	55	f5 − 6 U; U is not continually visible.	− 5.5

These observations made with the nine-inch refractor, using the smallest power, about 40. The last column contains the observed brightness of U Arietis in degrees of the scale.

It must be observed that until Feb. 8 the difference between *a* and *b* was estimated as equal to 6.4 degrees (Stufe) and after this time as equal to 15.7 degrees. I cannot explain the cause of this discordance: possibly the star *a* is also a variable.

I have plotted the observed brightness of U Arietis on millimeter paper, and have obtained the curve shown in the diagram. The maximum evidently occurs at the beginning of the year :

Max. = Jan. 1, 1893.

The minimum could not be observed because the star diminishing in brightness is gone in the evening twilight.

The double star *c* was measured in two evenings; the results will be published with all the measures made by me in Abastuman.

The longitude of the Georgiewsksja Observatory in Abastuman is equal to $2^h\ 51^m\ 19^s.5$ east of Greenwich.

EXPERIMENTS IN ELECTRIC LIGHTING.*

HEBERT A. HOWE.

Electric lamps of one candle power are now used so universally upon astronomical instruments that the results of experiments and research concerning the best methods of lighting them may be acceptable to those who have not studied the matter particularly. Three available sources of electricity suggest themselves at once, viz., the primary battery, the secondary battery, and the alternating current, which is so widely used for illuminating buildings. They will be discussed in order.

1. *The Primary Battery.*—The carbon-zinc batteries are thought to be the best for lighting purposes. However all forms of them need constant care, if they are to be kept in a satisfactory state of efficiency. The Taylor cell (Taylor Battery Co.—39 Dey St., N. Y.) is an excellent one, having an E. M. F. of 1.9 volts, and an internal resistance of only 0.08 of an ohm. A No. 2 cell, 8×6 inches in size, replaces 30 gravity cells, in running an Edison phonograph: three such furnish sufficient power to drive a sewing machine. The zinc is thoroughly amalgamated, and does not wast away, when the battery is idle. As there are no creeping salts the battery is clean. A No. 2 cell costs $2.50: its porous cup holds one pint of the depolarizing solution, which is good for 80 ampere hours, at a cost of four cents and a fraction. The fumes

* Communicated by the author.

of this battery are, however, very disagreeable: on this account it is well to enclose it in a box, from which a tube leads out of doors.

Another form of battery, which is said to give a powerful and steady current for a long time, and to be inexpensive in maintenance, is described in detail, with drawings, by Lieutenant C. D. Parkhurst in Bubier's Popular Electrician for August and September, 1892.

2. *The Secondary Battery.*—This is used by some who are so located that it can be charged easily by a direct current. I have never used storage batteries and do not know how true the statement is that the services of an expert are required to keep them in order. They are commonly reputed to be expensive and troublesome. It is claimed that the speedy disintegration to which such batteries are liable is obviated in a new form manufactured by the Ford-Washburn Electric Co., of Cleveland, O. There are no plates in this battery to buckle; the active material is contained in porous cups of special manufacture; the internal resistance is not far from 0.05 of an ohm. The battery is not injured by short circuiting, and remains in good condition for an indefinite period, when on an open circuit. Omnibuses are now lighted in London, with entire success by storage batteries weighing but eight pounds.

3. *The Alternating Current.*—If the Observatory be illuminated by the ordinary incandescent lamps on an alternating current, the house current may be used for the little lamps. This will be found to be the most satisfactory of the three methods. If the wire leading to any one of the house lamps be tapped, and one of the 1 c. p. lamps be introduced into the circuit, so that the current will flow through both of the lamps, the light given by the larger one will be decidedly dimmed, and the little one will glow. If the house lamp be now taken out, and a resistance box, having a capacity of from a hundred ohms downward, be inserted into the circuit with the little lamp, various degrees of brightness may be given to the little lamp by varying the resistance. After a series of experiments with resistance coils made of German silver wires ranging from No. 22 to No. 30, I came to the conclusion that the mere insertion of resistance did not give a satisfactory solution of the problem. Too much energy was consumed in heating the resistance coils: the cost of running a 1 c. p. lamp was not far from that of using a 16. c. p. lamp. Mr. Elbert G. Richardson, a Denver electrician, then offered to build a little transformer for me, to reduce the voltage of the house current

down to suit the 1 c. p. lamps. This converter is so simple, that I beg to describe it in detail. The core is a ring of ordinary stove wire, about 4 inches in external diameter, and 2½ inches in internal diameter. Such a ring may be made by winding the wire loosely around a good sized bottle. If the wire be rusty, so much the better, except for the man who does the winding. Bright wire may be varnished, and allowed to dry, before winding. Pieces of tissue paper occasionally inserted during the winding, for purposes of insulation, will add to the efficiency of the converter. Insulating tape is then wound around the core, covering the mass of wire completely. 1200 turns of double-cotton-covered copper wire No. 28 are wound over this (as one winds a string around his finger), the plane of each turn being perpendicular to the direction in which the stove wire underneath runs. The whole is next covered with insulating tape, except the two ends of the No. 28 wire are left out to be attached to the binding posts. The coil just put on is the primary, through which the house current is to run. The secondary coil of No. 17 double-cotton-covered copper wire is now to be wound on, in the same way as the primary wire. The number of turns of this wire is found by the following proportion.

The voltage of the primary current : that of the secondary current :: the number of turns of the primary wire : is to the number of turns of the secondary wire. The house current, which is to be utilized in the primary circuit has an E. M. F. of 50 volts usually. The voltage of Edison 1 c. p. lamps varies from 4 to 6 volts. If we wish the secondary current to have an E. M. F. of 6 volts, we have the following proportion for finding the number of turns of the secondary wire:

$$50 \text{ volts} : 6 \text{ volts} :: 1200 \text{ turns} : x\ (= 144) \text{ turns}.$$

The ends of the secondary wire are now attached to two binding posts, and the converter is ready for use. The wires leading to any one of the house lamps may be connected with the binding posts joined to the primary coil of the converter, while the wires from a 1 c. p. lamp are connected with the binding posts which are the terminals of the secondary coil.

It is easy to arrange matters by a two point switch, so that the current will either feed the house lamp, or the converter, at will; both can be run at the same time, if they are connected in parallel, instead of in series. If they are in series, so that the undivided current has to go through both, the 16 c. p. lamp will not glow at all, if the converter is well built, unless one of the small lamps is burning on the secondary circuit; if the secondary

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current be short circuited for a very few seconds, by joining its terminals (resting a knife-blade upon them), the 16 c. p. lamp will glow brightly. The converter may be permanently introduced into the house circuit, if desired, as very little current will get through it, when none of the little lamps are burning; but it is probably better to switch it off from the house circuit when no observations are being made.

A 1 c. p. Edison lamp consumes from 0.90 to 1.40 amperes of current. When this is glowing, if its voltage be 5, which is one-tenth of the E. M. F. of the house current, the current in the particular wires of the house circuit, which feed the little converter, will be only one-tenth as great as that flowing through the little lamp, provided that there are no losses in the converter. Mr. Richardson estimates the efficiency of the converter at 85 or 90 per cent. Hence a little rough figuring shows that the glowing of a 1 c. p. lamp causes a current of about one-eighth of an ampere to flow through the house wires. It is doubtful whether the house meter would be moved by so small a current. A house lamp usually consumes something over an ampere; so the use of a 1 c. p. lamp would cost about one-tenth as much as that of a house lamp, if the meter were sufficiently delicate to register the small current accurately.

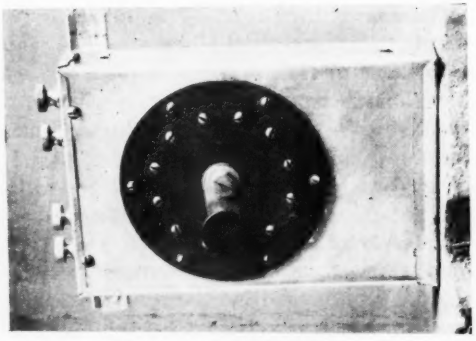

FIGURE 1.

Mr. Richardson arranged the converter which he built, so that it would give a current of the voltage of any particular lamp. The switch by which this is accomplished is shown on the face of the converter, in Fig. 1. The coils of the converter are enclosed in a stout tin box about the size of an oyster can, only the binding-posts and voltage switch being exposed. The top of the box, in which the posts are set, is a piece of vulcanized fibre.

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The circular piece of vulcanized fibre on the face of the box holds the studs on which the switch rests. The studs are merely short round-headed brass screws, screwed into the insulating material. The arrangement of the wires connected with the switch is shown in Fig. 2. By the proportion given above we compute that for 4 volts the secondary coil should consist of 96 turns of wire, and for 5 volts, of 120 turns. One end of the secondary is attached to the binding post B. B′ is the other post which is connected by a wire with T, the turning point of the switch. When the switch is turned so as to rest upon the stud 4, the E. M. F. of the secondary current is 4 volts; studs 5 and 6 give potentials of 5 and 6 volts respectively, when the switch rests on them. The secondary wire from B makes 96 turns before it reaches the point where it is joined to 4. This connection is made by scraping off the cotton covering of the wire at X, and soldering on a short wire, the other end of which is fastened at 4. Between B and Y are 120 turns, and between B and Z are 144 turns. The connections of Y and Z with 5 and 6 are made in the same manner as at X.

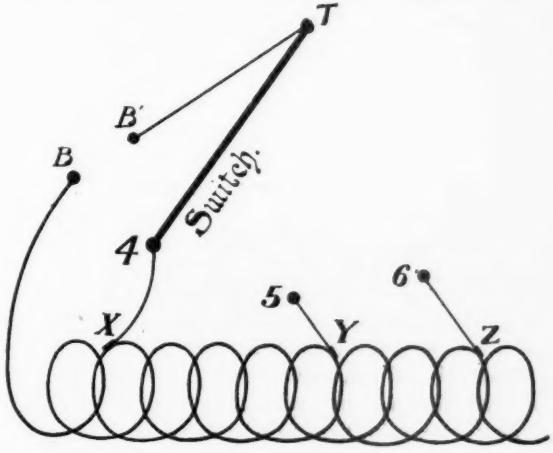


Fig. 2.

The switch may be utilized for varying the brilliancy of the light. If the voltage run from 4 to 6, it is a good plan to have every quarter volt between 4 and 6 represented by a stud, since a change of one-fourth of a volt makes quite a difference in the light. The number of turns for these intermediate voltages are readily computed. Where delicate regulation is required, as in the case of

a micrometer lamp, a small coil, giving variable resistance by means of a switch, may be attached to the lamp itself, or to the telescope, within easy reach of the observer.

The Edison lamps may be obtained with colored glass if desired. Green, blue, purple or amber lamps cost $1.10; ruby lamps cost $1.20; all of these have pear-shaped bulbs; the ones which I have examined measure one inch in length by half an inch transversely. Lamps with much smaller cylindrical or spherical bulbs cost twice as much. Lamps of 2 c. p. have a voltage ranging from 4 to 7 volts, and consume from 1 to 1.50 amperes. Those of ½ c. p. consume from 0.80 to 1.35 amperes of a current having an E. M. F. of from 3 to 5 volts. With each lamp is furnished a ticket giving its voltage and amperage.

In conclusion we may call to mind the advantages of using a little transformer; four may be enumerated: The labor of taking care of a battery is obviated; any desired number of lamps may be used at once, as in a house; the light is steady; the cost of maintenance is very small.

Mr. Richardson has consented to build a transformer suitable for all the lights used about an equatorial; it will be at the World's Fair, with Mr. Saegmuller's exhibits of astronomical instruments.

CHAMBERLIN Observatory, University Park, Colo.

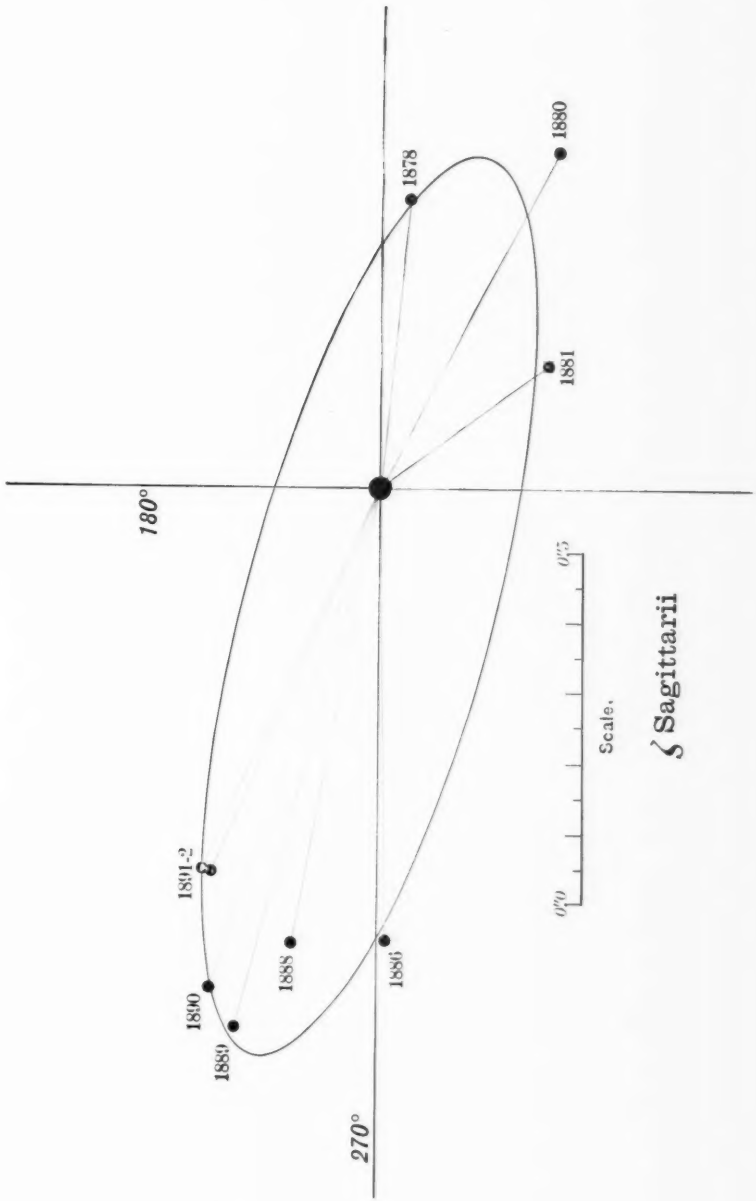
ON THE ORBIT OF ζ SAGITTARII.*

T. J. J. SEE.

In the *Monthly Notices* for 1886 (vol. xlvi, p. 444) Mr. Gore has given a first approximation to the elements of the orbit of ζ Sagittarii. This star has since been measured four times by Mr. Burnham at Mt. Hamilton, as well as by Leavenworth and Hall; and the additional data thus available seem to warrant the belief that a new determination of the orbit should give a much nearer approximation to the truth. Accordingly Mr. Burnham has selected all the measures which appear to be of any value and has drawn the accompanying apparent ellipse, from which the elements of the real orbit have been derived. It will, of course, be understood that this orbit is provisional, but it seems to be as good as we may hope to obtain from the data now available. Nor is it advisable to attempt anything like a definite

* Communicated by the author.

PLATE XXVIII.



determination, or an application of the method of least squares until the number of observations is very greatly increased. The apparent orbit seems to represent the observations very satisfactorily, and accordingly the real orbit is deduced directly from the apparent ellipse as shown in the figure.

Mr. J. W. Froley, a graduate student in astronomy of the University of Chicago, has, at my suggestion, determined the real elements by the graphical method of Klinkerfues. He finds the elements of the true ellipse to be as follows:

$T = 1878.62$	
$e = 0.30$	
$i = 73°.95$	
$\Omega = 75\ .35$	Elements of ζ Sagittarii.
$\lambda = 327''.35$	
$a = 0''.6800$	
$P = 17.715$ years	
$n = -20°.321.$	

It will be seen that the eccentricity is a good deal larger than that given by Mr. Gore (0.1698), and in this respect the present orbit conforms to the general rule among double stars. Mr. Burnham's apparent ellipse is based upon the following selected measures:

OBSERVATIONS OF ζ SAGITTARII.

t	ϑ	ρ	No. Nights	Observer.
1878.70	84°.2	0''.42	1	β
1880.62	62 .1	0 .55	2	ϑ
1881.61	36 .1	0 .31	2	ϑ
1886.62	271 .3	0 .65	4	Hl.
1888.66	259 .3	0 .67	7	Lv. & β
1889.41	255 .1	0 .81	5	ϑ
1890.49	251 .1	0 .76	3	ϑ
1891.53	246 .5	0 .61	3	β
1892 39	245 .1	0 .60	3	β

The elements given above represent these observations very well. The following are the computed and observed places:

ϑ_o	ϑ_c	$\vartheta_o - \vartheta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$
84°.2	84°.2	± 0°.0	0''.42	0''.418	+ 0''.002
62 .1	63 .4	− 1 .3	0 .55	0 .456	+ 0 .094
36 .1	37 .3	− 1 .2	0 .31	0 .290	+ 0 .020
271 .3	269 .6	+ 1 .7	0 .65	0 .657	+ 0 .007
259 .3	260 .8	− 0 .5	0 .67	0 .829	− 0 .160
255 .1	258 .1	− 3 .0	0 .81	0 .844	− 0 .034
251 .1	254 .3	− 3 .2	0 .76	0 .814	− 0 .054
246 .5	249 .9	− 3 .4	0 .61	0 .724	− 0 .114
245 .1	245 .1	± 0 .0	0 .60	0 .600	± 0 .000

This star will for the next few years be rather difficult to observe, but the great interest attaching to so promising a system ought to induce observers with large telescopes to give it careful attention. If it can be followed for a few years its orbit can be determined with the desired precision.

The UNIVERSITY of Chicago, 1893, May 16th.

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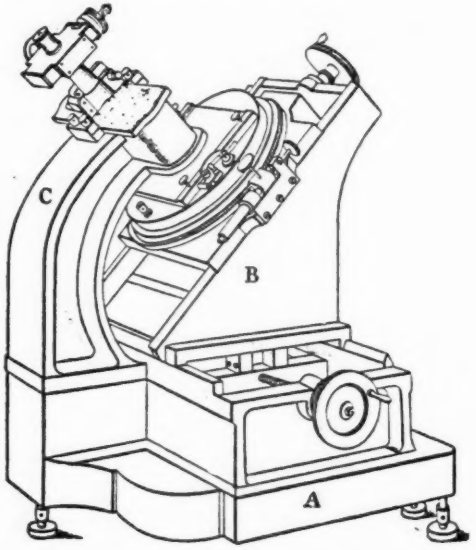
A NEW APPARATUS FOR MEASURING PHOTOGRAPHIC PLATES.*

The new apparatus, constructed by M. Gautier, was installed in May, 1892. This apparatus is a casting; it consists of a fixed horizontal piece *A*, furnished with two rails, on which slides an inclined plane at an angle of 45°, moved by a screw 0.18^m in length with a pitch of 0.005^m. On this inclined plane another screw of the same length as the first moves a cast frame, upon which is a movable circle, without graduations, carrying the fixed frame destined to receive the plates to be measured.



Each plate, when in place, is susceptible of three motions; a rotation, serving to orient in any required direction and two rectilinear motions, one of which is effected on the horizontal piece *A*, the other on the inclined plane *B*.

Each of the pieces *A* and *B* is furnished with a scale divided to millimetres, serving to count the turns of the screw. The curved piece *C*, which is cast with *A* terminates in a large groove designed to receive the microscope and micrometer box.

The heads of the two micrometer screws are divided to 100 parts. The value of one turn of each differs little from 1′; the tenths of divisions may be estimated, so that the readings may be made to about 0.06″

* From "Rapport annuel sur l'état de l' Observatoire de Paris, pour l'année 1892."

Astro-Physics.

THE SPECTRA AND MOTIONS OF STARS.*

W. H. S. MONCK.

In the preliminary volume to the Draper Catalogue (published after the catalogue itself), there is a table of stars whose spectra were re-examined with longer exposure in consequence of Vogel or Konkoly having arrived at a different conclusion from Pickering as to the character of the spectrum. The result is upwards of 200 corrections. Few of these affect the brighter stars, and there is consequently no appreciable error in my analysis of the Catalogue of Auwers. It was otherwise, however, with the Pulkova Catalogue and I found some other errors in my analysis of it. I therefore decided to send you a revised version omitting the stars common to both catologues, so that the results of the two investigations should be independent. The general effect of the changes are as follows: Several stars classed as A pass with longer exposure into class B, but they are all slow-moving stars, so that the motionless character of stars with spectrum B remains unaffected. Several stars classed as E pass into the class G as do also some of those classed as F. The result seems to be that stars with spectrum G undoubtedly belong to the Capellan, not the Arcturian type, and I shall treat them accordingly in the present article. Stars with spectrum M are also increased in number and, to a certain extent, in proper motion by longer exposure.

With this preface I give my revised results of the Pulkova Catalogue under the three heads of Sirian, Capellan and Arcturian stars. The superiority of the Capellan over the Arcturian stars as regards proper motion, and probably as regards nearness seems to me as well established as that of Solar stars over Sirians.

	No. of Stars.	Standard Motion over 1″.00	Standard Motion over 0″.50
Sirian	787	50	149
Capellan	246	93	139
Acturian	460	73	162
Type M	49	3	15

Of the stars classed as Sirian 42 have spectra of the class B. None of these has a standard motion (in N. P. D.) of as much as half a second annually.

The Cincinnati Catalogue contains stars with large proper motion only. I did not think it necessary to ascertain their stand-

* Communicated by the author

ard motion, which would generally be very considerable but thought it desirable to examine the spectra of the stars included in this Catalogue but not included either in Auwers' Catalogue or that of Pulkova. The result was as follows, Capellan Stars 85, Arcturian 62, Sirian 44. Of the latter *one* star (ξ Ophiuchi) has the spectrum B. I did not find any star with the spectrum M which had not occurred in either of the preceding catalogues.

That binary stars whose orbits can be computed are comparatively near to us will, I think, be generally conceded. I lately received from Dr. See a copy of his recent work on the subject which contains a larger number of orbits than any preceding catalogue. Comparing his list with the Draper Catalogue I identified 32 Capellan stars, 14 Sirians, 8 Arcturians and one with the spectrum M. The Arcturian binaries I may remark are extremely few. The spectra of four of the eight are marked doubtful in the Draper Catalogue and in two other cases (the well known stars 61 Cygni and γ Leonis) there seems to be a similar doubt as to the orbit.

What are we to infer from this state of facts as to the structure of the universe? That the solar stars (and I think I may now add the Capellan stars in particular) predominate among our nearer neighbors appears certain. But the opinion seems to be gaining ground that beyond the solar cluster the Sirian type predominates and that in particular, the Galaxy is mainly an aggregation of Sirian stars. The evidence available at present does not, I think, warrant any such inference. If indeed it were shown that the motions of the stars in the Galaxy, or of the Sirian stars generally, gave a different apex for the Sun's way from that derived from the motions of the solar and non-galactic stars (which have hitherto been chiefly employed for the purpose) we might reasonably conclude that we were dealing with two distinct star systems; while on the other hand, if we got the same apex (within the limits of probable error) from the two computations we might perhaps deduce the contrary conclusion. But the relative paucity of solar stars in any direction where faint stars are numerous admits of a very different explanation. A solar star is probably, on the average, a magnitude and a half fainter than a Sirian star of the same mass placed at the same distance from the eye. Let the Sirian star, for instance, be of magnitude 5.5. Its spectrum will probably be recorded in the *Draper Catalogue* which contains a majority of the Northern stars up to that magnitude. But the corresponding solar star will be of the 7th magnitude, and stars as faint as this very

rarely occur in the Catalogue. With greater power or longer exposure, these solar stars would appear, but unless we are able to look *through* the stars in this direction a number of additional Sirian stars will crop up at the same time still maintaining their numerical superiority. In short the solar stars whose spectra we are photographing are comprised within a sphere having only about half the radius of that containing the Sirians which appear on the same plate.

Results derived from Catalogues of proper motion are little more reliable. Suppose that among the known stars having a proper motion of between 0″.05 and 0″.10 annually, the Sirians predominate, who shall tell us how many faint telescopic solar stars are moving with this velocity? No inference can be drawn until our Catalogues are presumably complete; otherwise the greater brightness of the Sirian stars will give them an apparent supremacy which may prove wholly deceptive. As far as our certain knowledge reaches, solar stars preponderate. Whether beyond that limit Sirian stars assume the same relative superiority, is a problem of the future which we are not at present in a position to solve.

THE DISTRIBUTION OF THE STARS.*

MISS A. M. CLERKE.

The fundamental difficulty of stellar astronomy is that of rightly inferring the real from the projected places of the stars. Prolonged study is needed to show that they are not scattered at random over the sky. They shine down upon us as if flung loosely over the surface of a sphere, and indeed owe their name of "fixed" stars to the crude early notion of their being rivetted —*infixæ*—to the "palace-roof" they very effectually serve to adorn. Yet in reality this starry vault integrates, so to speak, immeasurable abysses of star-strewn space. There, as elsewhere, "things are not what they seem," and we are confronted with the inevitable question as to the relation between the thing that is and the thing that seems. From the aspect of the Milky Way came the first suggestion of an answer. The thought could not but present itself to intelligent inquirers that the dimly-shining girdle of the sphere might exercise a governing influence over its contents. Varied investigations of this obvious possibility were

* *Knowledge*, April, 1893.

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accordingly carried out, and the fact was established of a general increase of stellar density, gaining intensity with descent in magnitude, towards the galactic plane. The combination into a system was thus rendered probable of the sprinkled stars of the constellations and the streaming stars of the nebulous zone running through them; but no hint could be gathered as to the nature of the combination. Only the bare existence of some principle of arrangement was perceived by unsatisfactory glimpses.

Until lately the only practically available means of searching out the plan of stellar structure was by instituting comparisons between the numbers and the magnitudes of the stars. Average brightness, it was reasonably supposed, gave a measure of average relative distance, and from distance relative abundance per unit of space could be inferred by simply counting the successive photometric ranks. But the value of this method has been impaired by an advance of knowledge in two directions. In the first place it became evident, on a wider acquaintance with stellar proper motions, that their assorted amounts afforded a much surer test of distance than could be derived from the consideration of magnitude alone. Next, it came to be recognized that the intrinsic brilliancy of stars is very different for different spectral types, so that stars of the Vega type must be nearly three times more remote than stars like Capella or the Sun, equally massive, and possessing the same visual brilliancy. Diversity of stellar type implies then, diversity in laws of distribution—diversity, not only of the photometrical, but also of the physical kind, and hence constituting an essential feature of sidereal organization. The preponderance of Sirian stars in the Milky Way, simultaneously ascertained during the progress of Professor Pickering's spectrographic survey and of Dr. Gill's photographic Durchmusterung, appears to be a combined result. In part, it must depend, as pointed out by Mr. Monck, upon the crowding in of Sirian stars lying far beyond the limiting distance of the included solar stars; but there is reason to believe that it is also in part produced by a genuine relationship. What is certain is that it fits in with much that was already known, and provides a fresh platform for further inquiry.

It was in great measure through the labours of Professor J. C. Kapteyn, of Groningen, in measuring and reducing the Cape Durchmusterung plates, that the systematic difference in question was detected; and their conclusion has allowed him leisure to follow up the clue thus placed in his hands. He has done so by a re-

search into the distribution of the stars, with special reference to their spectral types, communicated to the Amsterdam Academy of Sciences in two important papers, read April 29th, 1892, and January 28th, 1893, respectively. The first, indeed, gave only preliminary inferences, but they were ratified and extended in the second by the discussion of a greatly enlarged stock of data. These related to 2357 stars, of which 1189 are classed in the Draper Catalogue of Stellar Spectra as of the first, 1106 as of the second, and 62 as of the third type. The proper motions of 476 of them were taken from the list prepared by Herr Stumpe for his determination of the solar translation; those of the rest from the Bradley-Auwers catalogue. The treatment of this material was on the principle that stars are, on a fairly wide average, distant from us in the inverse ratio of their apparent movements. So far as concerns the perspective element contained in them, this is of course strictly true, allowance being made for differences of angular position with regard to the apex of the Sun's way. That is to say, the line traversed in a given time by the Sun, if seen *square* from any star, would be of a length proportionate to that star's remoteness; and the transferred displacement of the star, as viewed from the Sun, would be equal and opposite to the proper displacement of the Sun as viewed from the star. Thus, assuming the direction of the solar translation known, and the "peculiar" movements of the stars to be so irregular as to give a zero effect when numerously thrown together, a secure measure is afforded of comparative stellar distance. Professor Kapteyn accordingly resolved his proper motions into two components, one directed along a great circle passing through an apex in R. A. 276°, Dec. + 34°, the other at right angles to it. The first, reduced to a position 90° from the apex, was treated as of wholly perspective origin; the second could not but be wholly original. And it was reassuring to find that their values (abstraction being made of a few exceptionally swift objects) varied in groups of stars arranged according to proper motion, pretty nearly in the same proportion. Either component, then, of stellar motion—the parallactic, or the peculiar—appears to supply a valuable criterion of stellar distance.

The initial difficulty connected with space-sounding operations being thus removed, a number of interesting conclusions lay, comparatively speaking, close at hand. Some of these had been anticipated by Mr. Monck, and their independent deduction, through a far more elaborate investigation, shows them to be deserving of no small credit. To begin with, the remarkable circum-

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stance seems fully established that stars with well-accentuated proper motions show predominantly spectra of the solar description.* Nor can we hesitate to agree that these objects owe their mobile character to their relative vicinity. They constitute, accordingly, a group which surrounds and includes the Sun. It is most likely roughly spherical in shape, and is so strongly condensed interiorly that a volume of space near its centre contains 98 times as many stars as an equal volume near its circumference. The maximum compression appears to be round a point† lying away from the Sun, towards the northwestern section of Andromeda, supposed by Professor Kapteyn to coincide with the centre of the Milky Way. But this identity is highly questionable. It depends —since the centre found for the cluster has a southern galactic latitude of about 20°—upon the truth of Sir John Herschel's and Struve's respective inferences of a position for the Sun, eccentric as regards the round of the Galaxy, and to the north of its medial plane. The brilliancy of the Milky Way, however, in the southern hemisphere affords in reality not the slightest presumption of nearness;‡ and Gould was unable, from a much more complete inquiry than Struve's could possibly be, to assign to the Sun either north or south galactic latitude. His situation, for anything that can be proved to the contrary, may be perfectly symmetrical within the great cosmical annulus. It cannot then be admitted, at least on the present showing, that the latter is concentric with the newly constituted solar star-group, which it may be remarked, has little or nothing in common with "Gould's cluster." This is projected in the form of a belt, and is largely made up of Sirian stars with slight or inappreciable proper motions; while Professor Kapteyn's collection shows no preference for the galactic, or any other plane, and includes only a slight sprinkling of "white stars," such as Vega, Sirius, Altair and Regulus, admitted because of the vicinity implied by their motions.

Beyond a certain limit of distance (estimated by proper motion), both Sirian and solar stars exhibit marked condensation towards the plane of the Milky Way. The former, indeed, much more than the latter; yet even solar stars, when remote enough to be sensibly stationary,§ obey the law of galactic attraction to an equal extent with the whole body of stars down to the ninth

* See Ranynard, *Knowledge*, Vol. XIV, p. 50; *Old and New Astronomy*, p. 798.

† The co-ordinates of which are R. A., $0^h\ 0^m$, Decl. $+42°$.

‡ Sutton, *Knowledge*, Vol. XIV, page 42.

§ With proper motion, that is to say, smaller than 0″.04.

magnitude. The distribution, accordingly, of second type stars is apparently regulated by two distinct principles; and the first, that of globular aggregation about the Sun, acts altogether independently of the second, that of galactic thronging. But how the sphere and the stratum resulting severally from the two kinds of influence are related, whether they are contiguous or widely separated, we have no means of determining.

Stars of the first type are more equably distributed. They are at least exempt from the tendency of their correlatives to concentration in the neighborhood of the Sun. On the other hand, they are drawn more strongly towards the Milky Way. They accumulate mainly into a disc, or possibly into a series of rings. The proportion of their numbers to those of second type objects grows rapidly with increase of distance. Outside a sphere, of which the radius corresponds to an annual proper motion of 0″.07, they are in a minority smaller and smaller as its centre is approached; outside of that sphere they claim about a two-fold numerical superiority. But is the superiority real or fictitious? We seem obliged to adopt the lattealternative. The disparity can, at any rate, be amply accounted fory the systematic difference in real brightness between the two great stellar orders.

Professor Kapteyn holds that there is no satisfactory evidence of their differing systematically in real swiftness. He has inves tigated the matter with a negative upshot. At equal distances, he finds Sirian and solar stars to be pretty equally displaced. The balance, that is to say, does not so far incline decisively either way. But at equal distances Sirian stars appear brighter by more than two magnitudes than solar star of similar mass. To send us the same quantity of light, they must then be 2.7 times more remote. Hence, obviously, an indiscriminate collection of stars exceeding a given magnitude represents the contents of a far larger volume of space as regards the first than as regards the second stellar order.* If the latter be included in a sphere of mean radius = 1, the former must be diffused through a sphere of radius = 2.7. The true proportion of their numbers, as compared with solar stars, would accordingly be increased in such a collection not far from twenty times! And the chief part of these adventitious stars, if they may be called so, would naturally fall into the ranks of immobile objects. To their presence, then, the excess of the first type spectra among the Bradley-Draper stars with evanescent proper motions may safely be attributed.

* This mode of reasoning has been anticipated by Mr. Monck.

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The leading results of Professor Kapteyn's able and exhaustive discussion may be recapitulated in the two following propositions:—

1. Stars with appreciable proper motions belong mainly to the solar spectral class, and gather round a point adjacent to the Sun, in total disregard to the position of the Milky Way.

2. Stars sensibly fixed, Sirian and solar alike, although not to the same extent, collect towards the galactic plane. Both types can hence be inferred to obey the same organic laws, and to be united into a coherent whole.

An unexpected peculiarity of distribution, indicated by this investigation, if not convincingly proved by it, is that stars of determinate magnitude of either type are on the whole more remote when situated in or near the Milky Way. It can only be explained as due to a greater prevalence of larger or more luminous bodies in that region than in other parts of the sky.

The general shape of the stellar universe is compared by Professor Kapteyn to that of the Andromeda nebula, as depicted in Mr. Roberts's photographs. The globular nucleus represents the solar cluster, the far-spreading rings or whorls the compressed layers of stars enclosed by the ring of the remote Galaxy.

[Professor Kapteyn's conclusion that Sirian stars appear brighter by more than two magnitudes than solar stars of similar mass is very interesting in connection with the evidence we already possess as to the relative density of Sirian and solar binary stars. The tables given on pages 796-7 of "The Old and New Astronomy" give 0.3094 as the mean density of the binary stars of known period whose spectrum is of the solar type, and 0.021 as the mean density of the binaries of known period whose spectrum is of the Sirian type—that is, solar binaries are on the average about fifteen times as dense as Sirian binaries.

So that, if Sirian stars and solar stars have photospheres of equal brightness, the Sirian stars will have on the average a diameter nearly two and a half (2.466) times as great as the diameter of solar stars of the same mass, and they would appear equally bright to us if situated at 2.466 times the distance of similar solar stars. In other words, the evidence derived from binary stars shows that Sirian stars appear to us nearly two magnitudes brighter than solar stars of similar mass.

Professor Kapteyn's general result seems to me to be involved in his assumption that proper motions are to be taken as the criterion of distance. This seems to me to involve the assumption that all types of stars are moving with the same average ve-

locity, an assumption which is not self-evident, but which seems, on the contrary, improbable in view of what we know as to certain types of stars being associated in clusters. Such clusters evidently form systems, and the individual stars cannot therefore have large proper motions relatively to one another, for such motions could not be controlled by the mutual gravity of the stars forming the system.

A solar cluster of swift-moving stars, such as Professor Kapteyn supposes, could not form a permanent system. The vast velocity which we know that our Sun and other stars having large proper motions are endowed with would carry them away from the centre of gravity of such a system, if it was composed only of the swift-moving bright stars we see. Their swift motions cannot be controlled by one or more dark stars of enormous mass, for the places of such dark attracting masses would be indicated by the symmetry of the motion of the bright bodies about them; and it is evident that such a solar cluster could not be held together by the attraction of rings of matter outside it.—A. C. RANYARD].

THE TEMPORARY STAR IN AURIGA.*

A. L. CORTIE.

The year 1892 will be famous in the annals of astronomy for two remarkable discoveries; the one, that of the fifth satellite of Jupiter, made by a trained astronomer, Mr. E. E. Barnard, on the night of September 9th, by means of the giant thirty-six inch equatorial of the Lick Observatory; the other, the subject of the present paper, made in the earlier part of the year by the Rev. Dr. Thomas D. Anderson of Edinburgh with such simple appliances as a small hand-telescope and a star-atlas. Whilst examining the constellation of Auriga in the last days of January, this gentleman observed a star of the fifth magnitude, or order of brightness, which at first he identified with the well-known star numbered 26 in maps and catalogues. Further scrutiny, however, and comparison with his star-atlas, revealed to him the probable existence of one of that rare class of celestial bodies, which attain but a temporary splendor, and then are seen no more. The information was therefore diffidently communicated to the Royal Astronomer for Scotland, Dr. R. Copeland, on the

* Communicated by the author.

morning of February 1st, by means of an anonymous postcard. The same night the orange-tinted stranger was sought for and easily found at Edinburgh, while at Greenwich the Astronomer Royal secured photographs of the star and of the surrounding neighborhood. The next day the telegraph wire had announced to the leading astronomers of the world, that a new star was to be seen in the Milky Way situated about two degrees to the south of χ Aurigæ, and preceding No. 26 of the same group of stars. The nearest bright star to the place of the Nova is β Tauri.

But an interesting fact was the result of subsequent examinations, suggested by Anderson's discovery, of star plates of this region of the heavens which had been taken in the preceding December by Professor Pickering at the Harvard College Observatory, and Dr. Max Wolf at Heidelberg. For while the star was absent from the photographs taken by the latter astronomer on December 8th, which showed stars of even the eleventh degree of brightness, it had two days later impressed its image on the plates of the American observer, as a star equalling in lustre those of the fifth magnitude. Hence it appears that in this interval of time it had risen through more than six degrees of brilliancy, thereby indicating a multiplication of its light and heat-giving powers in the proportion of one to two hundred and fifty. So distant too is it, that now that the Earth has completed since its first discovery more than two-thirds of its annual course round the Sun, the observations of Burnham and Barnard at the Lick Observatory have not succeded in bringing to light the slightest parallactic displacement of the object on the celestial sphere. Hence it is impossible to tell when the actual conflagration in the heavens took place, which was first recorded on the Earth on the night of December 10, 1891. It is no exaggeration to suppose that a star with a radiative power a hundred times greater than that of our Sun, commenced to send its message to us at the rate of one hundred and eighty-six thousand miles a second at least two centuries ago.

The discovery of temporary stars has hitherto been of very rare occurrence, the average being one for each of the last nineteen centuries. The first instance of which we have any record is that of the star discovered by Hipparchus, probably about the year B. C. 134. In this case we know the bare fact, and the interesting statement of Pliny that it was this discovery which induced the Greek astronomer to draw up his star-catalogue, the very first that has come down to us. Then there was Tycho

Brahe's famous star which blazed out in Cassiopeia in the year A. D. 1572, and was to be seen for a year and five months. Of this star it is recorded that its color changed from white through yellow to red, and then to white again, which furnishes us with some clue to a probable fluctuation in and recuperation of its light. In A. D. 1604 another Venus-like star, observable for a year, was discovered by the famous Kepler, while the same century furnished yet another example in Anthelm's Nova of A. D. 1670, which was to be seen for two years, the brilliancy fluctuating in a remarkable manner. The present century has been marked, including Nova Aurigæ, by five such apparitions; namely, in 1848, when a star was discovered by Dr. Hind in Ophiuchus; in 1866 when a star in the Northern Crown blazed up suddenly from the ninth magnitude to the fourth magnitude, and after again increasing its lustre six-fold in about three hours, finally became one of the class known as variable stars; in 1876 in the constellation Cygnus, a star of an orange-red tint which attained a lustre equal to that of a third magnitude star, and which according to an observation made by Burnham at Lick Observatory in the latter part of 1891, is a small star of 13.5 magnitude, and "at times seemed to resemble an exceedingly minute nebula,"* and finally in 1885 when a star just visible to the naked eye appeared in the very heart of the wonderful Andromeda nebula, with which, as observations seemed to show, it was physically and not merely optically connected. Of these recent stars, four have been subjected to spectroscopic analysis, and we shall have occasion to notice in the sequel some of the indications which they gave, but the Nova Aurigæ is the first star the light of which has been analyzed and permanently recorded for future study on the photographic plate. For the present we note with regard to these temporary or new stars the following common characteristics, suddenness of outburst, great rapidity in the attainment of their maximum of splendor, then decline, in some cases rapid, in others more leisurely, and finally in several cases a recrudescence of brilliancy.

It was not long after the news of the arrival of Nova Aurigæ had been bruited abroad, before its light was confronted by eye and by photometer, by photographic plate and by micrometer, and by that powerful engine of modern research the tele-spectrograph, or combination of telescope, spectroscope and photographic plate. It would be impossible within the limits of a single article to enter into all the niceties of, or indeed to give

* *Monthly Notices, R. A. S.*, vol. 52, No. 6, p. 457, April 1892.

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anything like a complete account of all the observations made on this interesting star. We must therefore be content to summarize the chief results of these observations, and in doing so we propose to discuss the history of the star in two sections, the first dealing with such results as were secured between its first appearance and its decline during the months of March and April, 1892, and the second with the observations made upon the star during its recuperation of brilliancy in the months of August and September.

With regard to the magnitude of the star we must, at the outset, distinguish between its magnitude as determined by eye or by the photometer, and that resulting from its images as impressed upon a photographic plate. For should the star be rich in rays to which the photographic plate is sensitive, but which do not affect the eye, the resulting magnitudes will be greater by the photographic than by the eye method of estimation. The magnitudes of the star during its first appearance have been studied among others by Pickering, Christie, Pritchard, Knott, Roberts, Stone, Burnham, Whitney, Gore, Baxendell, Lohse, Newall and Copeland, and the result of a comparison of such observations is that the photographic exceeds the visual magnitude of the star.* The earliest observations were those secured on Pickering's plates at Harvard College Observatory between the dates December 10th and January 20th, 1891. From these it appears that "the magnitude of the star on December 10th was 5.4," and that "the brightness increased rapidly until December 18th, attaining its maximum about December 20th, when its magnitude was 4.4. It then began to decrease slowly with slight fluctuations until January 20th, when it was somewhat below the fifth magnitude."† We have already noticed that it did not appear among the eleventh magnitude stars on Max Wolf's plate on December 8, 1891. Dr. Copeland too has "examined a large number of star maps and catalogues, ancient and modern, without finding any previous record of the new star."‡ Dr. Anderson is almost certain that he observed the star on January 24th, and twice in the following week, and that during the days preceding

* *Monthly Notices R. A. S.* vol. 52, No. 5, pp. 357, 366, 367, 371, No. 6, pp. 430, 432, 433, No. 7, pp. 508, 509: *Astronomy and Astro-Physics*, March, April, May, June, August, 1892: *Journal B. A. A.* March, April. Curves showing the fluctuations of the magnitude of the star are to be found in *L'Astronomie* for June, 1892, the *Journal B. A. A.*, for April, 1892, drawn up by the Rev. T. E. Espin, and in Dr. Copeland's paper reprinted in *Astronomy and Astro-Physics* for August, 1892.

† *The Observatory*, No. 187, April, 1892, p. 197.

‡ *Astronomy and Astro-Physics*, No. 107, August, 1892, p. 593.

the despatch of his postcard, it was of about the fifth magnitude. But since February 1st a series of systematic observations of the magnitude of the star has been secured. According to the Astronomer Royal it attained its maximum of brilliancy on the night of February 3rd, being then 3.5 as estimated from its photographic image, while Pritchard, at Oxford University Observatory, gives 4.82 by the photometric method, and Stone, of the Radcliffe Observatory, 4.4 by eye estimation, all three observers agreeing however as to the date of the maximum. This, then, was a second maximum. A steady loss of light then ensued until about March 16th, between which date and the 19th it again took a slight rise. Again a fall is recorded in the light-curve of the star, with a halting-point at magnitude six until March 8th, when it commenced to fall steadily and rapidly. By March 18th it had diminished to the ninth magnitude, on the 25th it was at the tenth, on the 28th it had fallen to the twelfth magnitude, and by the beginning of April it was a faint thirteenth magnitude star. It was clearly seen in the Lick telescope on April 24, "when it was of the sixteenth magnitude or fainter."* We have therefore in this first appearance a sudden outburst, a rapid rise to brilliancy, a fall, another rise to maximum lustre, again a fall, a third rise though less brilliant than its predecessors, and finally a rapid and persistent fall to extreme faintness. Moreover the star is rich in violet rays as shown by the excess of the photographic over the eye estimations of brilliancy.

The revelations of the spectroscope next claim our attention. On the very night of the announcement of its discovery, February 1st, Copeland, at Edinburgh, was able by means of a small spectroscope to detect the likeness of its spectrum to that of the Nova of 1866. "The C line was intensely bright, a yellow line about D fairly visible, four bright lines or bands were conspicuous in the green, and lastly a bright line in the violet (probably Hγ) was easily seen."† Glowing hydrogen was at any rate present in vast quantities as a constituent of the new star, while the lines in the green seemed to indicate a generic likeness between the Nova and that which appeared in Cygnus in 1876. On the night of February 2nd, Dr. and Mrs. Huggins commenced their study of the spectrum of the star, its spectrum was also photographed on February 3rd by Professor Lockyer at South Kensington and by Father Sidgreaves at Stonyhurst, and before a few days had elapsed from the announcement of the discovery its light had

* *Astronomy and Astro-Physics*, No. 108, October, 1892, p. 715.
† *The Observatory*, No. 186, March, 1892, p. 136.

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been analyzed either by the visual or spectrographic methods by many observers. Thus among others we have observations from Pickering at Harvard, Young at Princeton, Vogel at Potsdam, Campbell and Crew at the Lick Observatory, Bélopolsky at Pulkova, Maunder at Greenwich, Becker at Dun Echt, Copeland at Edinburgh, Eugen von Gothard at Héreny, Konkoly at O-Gyalla, and Espin at the Wolsingham Observatory.* An early paper on the spectrum was that presented by Professor Lockyer to the Royal Society, and dated February 4th, in which he announced the probable appearance in the spectrum of Nova of the three lines characteristic of the spectrum of the nebulæ, namely, the hydrogen line at F, the line near wave-length 500 in the green, which was coincident in his spectroscope with the radiation from burning magnesium wire, while a third line was probably coincident with the nebular line 495. The carbon fluting at 517 was also represented. The hydrogen C line was present and of great brilliancy, a feeble line in the yellow was near the place of the sodium line D, and a photograph of the spectrum showed thirteen additional lines, among them being the hydrogen lines at G′, *h*, and H. Now, according to Professor Lockyer's researches into the constitution of meteorites, the spectrum of these bodies always shows first the hydrogen spectrum, then as the temperature is increased the spectrum of carbon, or one of its compounds, while at a still higher temperature the magnesium spectrum begins to appear. According to the "Meteoritic Hypothesis" of the same spectroscopist, the spectra of those nebulæ which consist of bright lines, can be matched by the spectrum of meteorites, for the line near 500 coincides with a low temperature magnesium fluting, and the hydrogen line F is certainly present. Temporary stars too according to this hypothesis give a spectrum which is identically that of the meteorites, and their origin is to be ascribed to encounters between the constituents of two meteor streams which, as Professor Lockyer suggestively expresses it, meet at a "level crossing." We have thus early in our summary of the spectroscopic observations called attention to Professor Lockyer's observations and theories as we shall have afterwards to compare them with the results of other observers, in our endeavour to find some solution for the riddle, and it is a great one, set us by the spectrum of the Nova of 1892. Luckily we have observations over every portion of the extent of its spectrum, which extended from the extreme red even below the C line

* Published in the *Proceedings R. S.*, the *Monthly Notices R. A. S.*, *Astronomy and Astro-Physics*, *The Observatory*, *Nature*, *Astronomische Nachrichten*, *etc.*

according to observations of Professor Young, and of Dr. and Mrs. Huggins, to that limit in the ultra-violet where the light of celestial bodies ceases to overcome the absorptive effect of our atmosphere, as was shown by the photographs taken by the last-named observers. As is well known, the ordinary photographic plates are only sensitive either in the violet or in the blue; beyond F we have to depend for the most part on visual observations through the green, yellow, orange, and red portions of the spectrum. The plates used at Stonyhurst, however, were those which are rendered by the use of suitable dyes sensitive also to green light, and Father Sidgreaves' photographs extend from D in the yellow to H in the violet, thus admirably supplementing those of other observers.

The first fact then about the spectrum of Nova Aurigæ is that it was of great extent, and not confined to any particular colour or colours, unlike the spectrum of Nova Andromeda in 1885, which was, allowing for the difficulties of observation, mainly confined to the green. Moreover, throughout its whole extent the spectrum was full of lines, both bright lines and dark lines, and these again were contrasted with the background of a well marked continuous spectrum. To give some idea of the number of lines which the stars showed there were nearly sixty well marked and unmistakable bright and dark lines or bands in the Stonyhurst photographs, which under a powerful microscope after a week of study independently resolved by at least two observers into more than two-hundred lines, the spectrum being a most complicated one. The maps drawn by Dr. and Mrs. Huggins in those parts which are supplementary to the Stonyhurst photographs, furnish about forty other lines.* Dr. Becker too, at Dun Echt, measured seventy-one bright lines in the visible portion of the spectrum and a very extensive catalogue of lines has recently been published by Professor Campbell. So that our second fact with regard to the spectrum of Nova Aurigæ is that it was rich in bright and dark lines.

Many of these lines too, were of great breadth, notably, those of hydrogen, the F and G′ lines extending over several tenth-metres. These lines seemed to be also sharper on the side towards the violet end of the spectrum, and more diffuse on that turned towards the red end. They presented the appearance characteristic of the lines of the gas, when it is under great pressure and of great density. It has been objected that this immense broadening of the lines was possibly a photographic effect due partly to the

* Proceedings of the Royal Society, vol. 51, p. 493.

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necessarily long exposures, and partly to the scintillation of the star.* But a series of experiments undertaken for the express purpose of the solution of this question by Father Sidgreaves on γ Cassiopeiæ, and other stars, has proved that the effect in Nova is not photographic, but has a true physical cause to be looked for in the constitution of the star. In 1879 and succeeding years Dr. Huggins took a series of photographs on the ultra-violet spectrum of Sirius, Vega, and other bright white stars, and his plates showed besides the well known hydrogen series G′, *h*, H, of the violet, nine other lines of similar appearance and arranged in rythmical order. The detection of these lines in the stars led to laboratory experiments, and they were identified by Lockyer, Vogel, and Cornu, as all forming part of a harmonic series and due to hydrogen. The quite recent advances in the study of the solar atmosphere made by Hale at Chicago and Deslandres at Paris, by means of photography, have added these same lines, and five others in addition further removed still to the violet, to the hydrogen lines of the Sun. Now Dr. and Mrs. Huggins' photographs of the ultra-violet spectrum of Nova Aurigæ, show this same series of lines in the spectrum of the star. We cannot thence conclude that Nova Aurigæ was a star like Sirius or other stars of Secchi's Type I; for in addition to these lines, which we now know to be proper to the Sun also, the spectrum of Nova was, as we remarked before, full of lines from the extreme red to the extreme violet. Was the spectrum then like that of our Sun in its other details, and could it therefore be relegated with the Sun and other yellow stars as Aldebaran, Capella, Pollux and Arcturus to Secchi's Class II? But we have already seen that Professor Lockyer identified in the new star the nebular triplet in the green, the lines of hydrogen and a carbon fluting. The point then as to what gases or metallic vapors the lines were attributable needs careful consideration. And first, the weight of evidence is entirely against Professor Lockyer, with regard to the presence of the chief and characteristic nebular line and the carbon spectrum; though of course all observers are agreed that the hydrogen formed a marked constituent of the blaze of the new star. The absolute position of the chief nebular line near 500 has been determined with great exactitude by Professor Keeler with the magnificent apparatus at Lick Observatory. The number given by this observer is 5005.93.† The position of the very bright line near 500 in the Nova which was ascribed to the nebular spectrum by Profes-

* The Observatory, No. 187, April, 1892, page 165.
† Proceedings of the Royal Society, vol. 49, p. 401.

sor Lockyer, was likewise independently determined by other observers. Dr. Huggins placed it at 5014, Professor Young at 5015, Father Sidgreaves at 5014, Professor Vogel at 5016, Herr Eugen von Gothard at 5019, Herr Konkoly at 5019.5 while the observations of Dr. Becker, Professor Campbell,* and M. Bélopolsky agree in locating the line in a position removed far to the red side of the chief nebular line. But, as we shall see hereafter, the light source was moving away from us, and just as the tone of the whistle of a locomotive is lowered in pitch as it rushes away from a listener at rest, so too analogously with light waves, if the source of light is receding from us the color tone will be lowered, and its luminous spectral rays thrown down towards the red in the scale of colors. Might not this cause have been operative in shifting the bright green nebular line some eight or ten places from its normal position? But Dr. Huggins confronted the analyzed light of the star in his spectroscopes with the spectrum given by nitrogen and the vapor of lead, the relative positions of certain lines in these substances to the chief nebular line being known with very great accuracy. Even allowing for the shift due to the velocity of the light source in the line of sight, the result of these experiments was to negative the existence of the chief nebular line in the spectrum of Nova. Nor was the second nebular line to be found in its spectrum according to the witness of most observers, although as with line 500,† so with line 495, there was a faint line suspiciously near in position, but not to be confounded with it. Professor Campbell saw such a line; Dr. Becker measured a line at 4947, Dr. Copeland at 4952.5, which however he states was not the nebular line; on one of the Stonyhurst plates, too, but on one only, there appeared a broad faint bright line at 4954. On the other plates the region in the immediate neighborhood of 495 is occupied by continuous spectrum with dark lines superposed upon it. Dr. Huggins also remarks the absence from Nova "of a very strong ultra-violet line which is usually found in the spectrum of the nebula of Orion."‡ Direct comparisons, too, of the spectrum with the hydro-carbon and carbon oxide flame and with magnesium led to negative results as to the presence of these substances in the star.

Before we proceed to discuss further what substances were probably represented in this remarkable spectrum, our attention

* The position given to the line by this observer in a recently published paper, *Astronomy and Astro-Physics*, No. 109, p. 805, Nov. 1892, is 5018.

† One photograph of Professor Campbell's taken on Feb. 14, gave a line at 5007. (loc. cit.)

‡ *Loc. cit.* page 488.

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is demanded by some other of its peculiarities. And first a great number of the brightest lines and noticeably all the hydrogen lines, were accompanied on their blue sides by a dark counterpart so that the appearance of the spectrum, considering these lines alone, was that of a series of bright and dark couples. This was indeed a curious fact, but more than this, upon the bright lines which had these dark companions, appeared thin dark absorption lines. Thus to take the F line of hydrogen on the Stonyhurst photographs as an example. Proceeding from blue to red, we have first a broad black absorption line of dark hydrogen, then a broad line of bright hydrogen which was divided unsymmetrically by a dark absorption line, the line of division leaving more of the brightness to the blue than to the red side. The line was finally terminated on the red side by a sort of nebulous wing. Turning now to the G′ or first violet line of hydrogen, we have the same broad divisions as in F, but with this difference, that each component of the bright G′ is subdivided by dark lines, the blue bright component by one, and the red bright component by two dark lines. Moreover, alterations took place, either by changes in the relative brightness of the two bright components of F, or by the incoming of sharp dark lines on the bright bands or of sharp bright lines on the dark bands, after the star had attained its maximum. This fact is testified to by the observations made or by the photographs taken at Tulse Hill, Potsdam, Stonyhurst, the Lick Observatory, Pulkova, and Harvard College. If the lines of any substance are thus doubled, and let us take the hydrogen line F as our example, it is clear that the normal position of the line in a body at rest must coincide with either the bright or dark component, or with neither. Wherever the normal position of the line F for example, might be with reference to the remarkable F line given by the Nova, the dark and bright hydrogen must have been in relative motion to one another. This relative velocity of the bright and dark gas was exceedingly great, about five hundred and fifty miles a second according to the measurements of Dr. and Mrs. Huggins, Professor Vogel and Father Sidgreaves. More remarkable still, there was no change in this velocity for more than a month.

It must be evident even to those who are least conversant with the niceties of spectroscopical researches, that before a map can be constructed from measures, made either with the telescope or from photographic plates, which shall accurately represent the true positions of the lines in any spectrum, we must needs settle with very great accuracy the true position of some fiducial or

starting-point. Nor can any theory of the star, its constituents or its origin, be formulated unless the positions of the lines are absolutely correct. In the Nova the lines of hydrogen were certainly present. The spectrum of hydrogen can be very easily obtained in vacuum tubes by means of electrical excitation. The standard positions of the lines of hydrogen are also exactly known. One obvious method then of fixing a starting or fiducial point was to confront the spectrum of the star with the spectrum of hydrogen, and to determine where, for example, the F line of hydrogen as given by the tube was situated relatively to the enormously broad and complicated double F line of the star's spectrum. This was the method adopted by such experienced observers in this line of work as Dr. and Mrs. Huggins, and Professor Vogel. With regard to F, Dr. Huggins writes, "The line from the vacuum tube fell not upon the middle of the line (*i. e.*, the bright broad F in the Nova) but near its more refrangible (*i. e.*, blue) edge."* Professor Vogel states, "These three lines (*i. e.*, C, F and G′) did not exactly coincide with the lines of the comparison spectrum, but were displaced considerably towards the red, without, however, separating completely from the artificial lines, since they were very broad."† At any rate, from these statements it appears, and we may add the concurrent testimony of Eugen von Gothard, that the bright F of the tube did not fall upon the dark but upon the bright hydrogen, although Dr. Huggins would seem to place it slightly more to the red than Professor Vogel. Father Sidgreaves argued that the proper place for F on his photographs taken with a prism, would be that position in the complicated Nova line, which gave the proper wave-length intervals F to G′, and G′ to *h*, in other words which would give the best fit. He found after many and careful experiments that "the marginal separations of the bright and dark parts of the hydrogen broad lines at F, G′, and *h* are the only similar positions in each that give the correct wave-length intervals F-G′ and G′-*h*: in other words, the true positions of these lines are those which are common to both the bright and dark parts."‡ Thus he differs from Huggins and Vogel, who make the true positions of F, G′, *h*, as proper to the bright part, although indeed their positions are not very far removed from his. He also admits as telling strongly against him an observation of Professor Young made on the C and F hydrogen lines in a perfect instru-

* *Loc. cit.* p. 486. The explanatory words in brackets in all quotations are ours.

† *Nature*, vol. 45, No. 1169, p. 498, March 24, 1892.

‡ *The Observatory*, No. 193, p 364, October, 1892.

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ment of great dispersion. According to this observer "the lines were diffuse, like C and F from hydrogen under pressure; but the shading was sensibly symmetrical each way from the *middle of the line.*"* That is, with Huggins and Vogel the true position of F is in the bright line of Nova and proper to it, but still further removed to the red than they would place it. Starting from the middle of bright F we might arrange the order in the observations thus, Young, Huggins, Vogel, all making the fiducial point proper to bright F, and Sidgreaves placing the fiducial point as common to bright and dark F, and at the separation of the bright and dark lines.

We may now ask if the nebular lines, and the hydro-carbon bands are excluded from the spectrum, and in their exclusion Professor Vogel by direct comparisons concurs with Dr. Huggins, what spectrum most completely answers to the spectrum of Nova? We answer unhesitatingly the spectrum given by the chromosphere and prominences of our own Sun. First we have the full hydrogen series, which we have already pointed out has been observed even in its ultra-violet radiations by Hale and Deslandres as belonging to the solar prominences. Then the two bright lines at 5014 and 4921 which together with *b* formed the bright triplet in the green which was so conspicuous to all observers, are matched exactly by solar chromospheric lines. The characteristic Sun line D_3 was also present, the sodium couple D, and very probably one if not all the lines of the triplet *b* of magnesium. More than this, if we take the list of chromospheric lines of the Sun as observed by Professor Young and collate them with the bright lines of Nova, there is a striking accord both in position and character between the two sets of lines.† Nor does the likeness of the lines in Nova to those observed in the chromosphere and storms of glowing gases and vapours frequently observed in the Sun end here. For, to mention no others, M. Deslandres at Paris has observed in the lines which are brightened in the solar atmosphere precisely the same doubling of bright by black lines as was seen and photographed in the spectrum of the Nova. And, further still, the incoming of these bright or dark lines upon the broad dark or bright bands is perfectly represented in the spectrum of solar storms and Sun-spots. Again, with regard to the unsymmetrical division of some of the broad bright lines by

* *Astronomy and Astro-Physics*, April, 1892.

† Father Sidgreaves first called attention to this point of the probable numerous coincidences of chromospheric and Nova lines at the May meeting of the R. A. S. See *The Observatory*, No. 189, p. 236. In his recent papers, *loc. cit.*, Professor Campbell gives a long list of such coincidences.

dark absorption lines, the same effect has been produced by Professors Liveing and Dewar in the laboratory in their experiments on the spectra of the vapours of metals. So that all the indications of the remarkable spectrum of the new star seem to suggest rather a solar chromospheric than a nebular analogy. It would be premature, however, to conclude that the new star was a body constituted like our Sun. Its feeble continuous spectrum, relatively to the intense luminous radiations of its atmosphere, would seem to preclude any such probability. More likely it might be specifically reduced to that class of variables, which includes stars such as γ Cassiopeiæ, β Lyræ, and η Argus, which likewise exhibit the bright chromospheric solar lines. In fact, with β Lyræ it has a very strong family likeness, for this star too gives a spectrum characterized by the same strange doubling of the bright and dark lines. Nor must we neglect the fact that when the Nova of 1876 was dying out, it showed this same line near 500, which if not the nebular line, can be so easily matched by a group of bright chromospheric lines.

We may now proceed with the history of the second appearance of this interesting star. We left it at the end of April as a faint glimmering of light in the Lick equatorial and reckoned to be of the sixteenth magnitude. It was, therefore, with somewhat of surprise that astronomers learned by means of a circular from the Rev. T. E. Espin, of the Wolsingham Observatory, that Mr. H. Corder had, on observing the place of the Nova on August 19th, ascertained that it had again increased in brightness, and was on that date of about the ninth magnitude. In other words, this remarkable object, which at the end of April had possessed but the 1-60,000th part of its radiative energy of the beginning of February, had again increased its brilliancy of August eight hundred and eighty-five fold. The Harvard College observers, who on April 26th gave to the star a magnitude 14.5, reckoned on the 24th by the Lick observers as of magnitude sixteen, now regarded the star during the month of August and the beginning of September as being of the tenth magnitude, the visual magnitude, contrary to what was before observed, being now somewhat greater than the photographic. From this last fact it can be inferred that the star's light was in great part of that quality which predominates in the visual part of the spectrum. On August 30th the Astronomer Royal's photographs made the star of the twelfth magnitude, while the visual observations of Freeman, Copeland, Küstner, Ristenpart, Burnham, Krueger, and others agreed in placing the magnitude about the number ten. Even on

September 14th it was about the same magnitude to Mr. Newall in the Cambridge twenty-five-inch telescope.

With regard to the spectrum, the Rev. T. E. Espin announced that its light was monochromatic and that the spectrum consisted of a brilliant line, the perplexing line in the green near 500. Herr Bélopolsky, at Pulkova, detected two lines, the one a green line, the mean of measures made on five nights placing it at 501, and the other too variable in brightness for satisfactory measurement. Dr. Copeland and Mr. J. G. Lohse, with the Dun Echt fifteen-inch refractor, measured the two lines as being situated at 5003 and 4953, in other words, they seemed to be the two lines characteristic of a gaseous nebula. Subsequent observations revealed a distinct line in the yellow near 5801, about the place of a line seen in 1876 in Nova Cygni, and to be found in a certain class of bright line stars. The star also showed a faint continuous spectrum in the green. Herr Bélopolsky also recognized a yellow line, which he presumed to be D or D_3, F of hydrogen was also visible, and a dark line about 465. In the Cambridge twenty-five inch Mr. Newall saw a bright line near C of hydrogen, three bright lines close together in the green, a faint bright line in the blue presumably F of hydrogen, and a still fainter line in the violet. The continuous spectrum was recognized, but no dark lines. Later observations showed the line in the red, and the green triplet, while the blue and violet lines had faded away. Finally, on October 14th, the red line being fainter, the yellow line, possibly 5801, was brighter. These observations of Newall are important as connecting the general appearance of the spectrum of this tenth magnitude star with that observed on March 24th by Dr. and Mrs. Huggins, when the star had fallen to nearly the eleventh magnitude. For on that date "the four bright lines in the green were distinctly seen, and appeared to retain their relative brightness; F the brightest, then the line near *b*, followed by the lines about 5015 and 4921. Traces of the continuous spectrum were still to be seen."* Turning now to the photographs of the spectrum, Professor Pickering, whose plate of March 21st gave the hydrogen lines G′, F, H, *h*, in the order of brightness named, on September 2nd photographed two lines of equal brightness, G′ of hydrogen, and the other near 500. Herr Gothard, at Hereny, compared his spectrograms with the lines given by the bright-line Wolf-Rayet stars, and the Ring nebula, with the result that a satisfactory agreement was detected between them. Finally Professor Campbell, at Lick, observed or

* *Loc. cit.* p. 492.

photographed eleven lines, among them being the hydrogen lines F and G′, and at least nine of the eleven lines, according to his measures, being found in the nebular, or bright-line star spectrum.* The lines 5002, 4953, and 4857 he regards "as undoubtedly the three nebular lines, displaced towards the violet. . . . The nebula is therefore approaching us with a velocity of at least one hundred and seventy-five miles a second."† Professor Barnard too recognized with the Lick equatorial the visual appearance of a planetary nebula in the new star, a result, however, which neither Mr. Newall or Mr. Roberts can succeed in verifying with their instruments, while Mr. Newall suggests a very plausible explanation for the nebulous appearance of the star in the Lick telescope.‡ Must we then conclude that the Nova has become a planetary nebula? In spite of the great and acknowledged skill of Messrs. Campbell and Copeland in spectroscopic researches, we remain not quite satisfied on the point. And first we must remember that the star at its second outburst was very faint, and that to measure the position of bright lines in a very faint star is by no means an easy matter, although it may be justly urged that in the present case the measures of the two green nebular lines as given by the two independent observers are most concordant. In the next place, of Professor Campbell's list of eleven bright lines, which are found in nebulæ, seven are recorded as covered by, or lying upon the edges of bright lines photographed at Stonyhurst in February, while another is very close to the position of a line measured by Dr. Becker in the same month. In fact, the only line that cannot be satisfactorily accounted for is the conspicuous green line near 500. But even with regard to this line the mean of Bélopolsky's measures place it at 501, very near indeed to its old position, while to Campbell himself it seemed, in a powerful grating spectroscope, to be a very broad line or band. We may also remark with regard to 495 that the map drawn by Dr. and Mrs. Huggins, in March, shows two lines very close to this position. Then we have the similarity in general appearance of the spectrum of the waning and waxing star, as witness the observations of Dr. and Mrs. Huggins and of Mr. Newall, and finally the testimony of the Lick observer, that when observed in August the "continuous spectrum presents the ap-

* In a more recent paper, *Astronomy and Astro-Physics*, November, 1892, he records the identification of the two outstanding lines in nebular spectra.

† *Astronomy and Astro-Physics*, October, 1892.

‡ The opinion of observers at the November meeting of the R. A. S. seemed to be that the telescopic appearance of the star was unlike that of other stars in its neighbourhood, though it could not with certainty be described as a planetary nebula.

pearance of containing a large number of bright lines, just beyond the power of the telescope to define."* At least then we may conclude that the evidence, and the probability founded thereon, of the spectrum of August and September containing the nebular lines, is of much lower weight to the almost concurrent evidence of observers, and the corresponding high probability of their non-existence in the earlier spectrum.

But how are we to account for the various phenomena optical and spectroscopical presented by this remarkable new spot of light in the Milky Way? For any theory of the new star's origin and physical constitution must needs find an explanation for the sudden outburst of light, for the fluctuations, the wanings and the waxings of the light, for the wonderful spectrum, its extent, its multitude of lines, its complexity, the bright lines with their dark companions, the enormous relative velocities indicated by the same, and the long continuance of these velocities without any appreciable alteration. Swarms of meteorites meeting at a level crossing are excluded by the absence of the carbon and magnesium lines or bands from the spectrum. So too are all theories based on the assumption of a star rushing away in our line of sight and moving through a nebula coming towards us, for the nebular lines were not present in the earlier spectrum, and their appearance in the later spectrum is problematical or at least not proven.† But in discussing the spectroscopic appearance of the star we have pointed out the many analogies with the spectrum of the solar chromosphere and prominences, and, be it remarked in passing, the hydrogen spectrum, whatever else was present, was a marked characteristic of the later appearance of Nova. Was it due then to two bodies composed of materials like our Sun colliding in space? In that case the energy of motion being converted into energy of heat, the solid bodies would form a violently agitated and rapidly expanding gaseous mass, which, after a series of contractions and expansions, would finally become a Sun-like orb. The initial outburst of light might thus be accounted for, but it is difficult to see, the total amount of radiative energy remaining the same, how the fluctuations of the star's light and its rapid dissipation could be thus explained. But if the conversion of external energy of motion into energy of heat is excluded, we must turn to the pent-up internal energies of the heav-

* *Loc. cit.*

† After reading Professor Campbell's more recent papers we are inclined to modify this opinion, and to think that if the later spectrum contains lines near 500 and 495, then they were probably present in the earlier spectrum, but masked by dark bands, as indeed some observations mentioned above seem to indicate.

enly bodies, to inquire how they could be liberated. This is Dr. Huggins' explanation of the phenomenon, a further advance on a theory due originally to Klinkerfues and afterwards developed by Wilsing. Conceive two bodies in different stages of evolution, but still of the solar class, to be travelling through space with enormous speed, such a speed as puts at defiance the universal law of gravitation, accepting the word universal as limiting the application of the law to our own known system or universe, such a speed as is displayed by the so-called run-away stars Arcturus and No. 1830 of the catalogue of Groombridge. Moreover, let us postulate that they are moving in hyperbolic orbits, and again that these orbits are performed in planes not very much, if at all tilted to our line of sight, these last two postulates being well within the limits of possibility. What will occur if furthermore these two bodies pass sufficiently close to one another. On the Klinkerfues-Wilsing hypothesis, they will mutually deform one another, set up tides in the gaseous materials of which they are composed, and induce such differences of pressure in their respective atmospheres as will be capable of producing enormous eruptions from the hotter interior layers of the two globes. Thus would the chromospheric lines, the number of lines, the hydrogen spectrum, the reversal phenomena, the sudden outburst of light, its fluctuations, and its final waning be accounted for. And the two stars are only to be supposed to be rushing the one towards us, and this one giving the dark lines superposed upon the faint continuous spectrum, and the other, which gave the bright lines, receding from us, and we have the curious matching of bright by dark bands, and the observed displacement of the lines from their normal positions. The permanence of this displacement can be met by the assumption of the motion of the two bodies as having taken place in hyperbolic orbits, so that after their swing round one another, the components of their velocities in the line of sight would continue nearly constant for a long time.

But these high velocities and their continuance without apparent change for several weeks, as well as the one body having been, so to speak, a dark replica of the other, are very great difficulties in the way of the acceptance of Dr. Huggins' theory in its entirety. Accordingly Father Sidgreaves has proposed a modification of the theory, by which we get rid of these somewhat unsatisfactory factors. The foundation, however, of his explanation rests upon the fiducial line F being at the point common to both dark and bright F in the Nova and not in the bright F, a question which we have already sufficiently discussed, and the bearing of

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which upon the theory of the new star is important. According to Father Sidgreaves then, the original upset of equilibrium may be attributed to the casual passing of one body near another, as actual collision seems to be excluded, but the whole of the phenomena visual and spectroscopic are to be attributed to the light of one body, and not to the integration of the light of two. In other words, we have a cyclonic storm similar to those seen in the Sun, but on a very much greater scale. "A great cyclonic storm of heated gases would produce this double effect (*i. e.*, the dark lines matching the bright lines), if the heated gases were rushing towards us in the lower depths of the atmosphere, trending upwards, and returning over the stellar limb. In the lower positions the advancing outrush would be screened by a great depth of absorbing atmosphere (hence the dark lines), while as a high retreating current its radiation would be along a clear line to our spectroscopes" (the corresponding bright lines).* Certainly M. Deslandres has seen such appearances in solar prominences, while other solar observers can testify to the reversals of lines in prominence and Sun-spot spectra corresponding to those observed in the bands of the Nova. Nor are the velocities on this hypothesis greater than some observed in solar storms by Father Fényi of the Observatory of Kalocsa. But a difficulty is furnished by the case of the star β Lyræ. It too shows these curious dark and bright companion lines, but the bright lines, according to Professor Pickering, alternately and periodically appear right and left of the corresponding dark lines. We cannot possibly suppose this periodic shifting to be the result of periodic storms, with the bright gases alternately rushing up and down. Other considerations too seem to show that the fluctuations in the light of β Lyræ are due to the action of two bodies. And β Lyræ is a variable star, so too is T Coronæ, the new star which appeared in 1866, and was the first to be subjected to spectroscopic analysis, and which also showed the dark flutings characteristic of Secchi's Type III of stars, to which type or class a very large proportion of variables are to be referred. Again the Sun itself is a variable star, the variation of light and heat being, it is true, on a small scale, but yet the curve of Sun-spot frequency bears such a striking resemblance to the light curves of many variables, that it is impossible not to see a common or related cause for the phenomena of spot-variation in the Sun and light-variation in the stars. So that the Sun may be connected through the link of variability both with temporary and variable stars. And yet the Sun ac-

* *The Observatory, loc. cit.*

cording to the celebrated speculation of Kant and Laplace, a speculation which has received in these later years a much firmer basis of probability from the thermodynamic calculations of Lord Kelvin and Professor Helmholtz, and from the knowledge of the cosmos acquired by means of the camera and the spectroscope, was originally formed from a gaseous nebula. If then it should be established that the Nova of 1892 really re-appeared after its first decline in light as a planetary nebula, and, be it noted, that of 1885 appeared in the midst of a nebula, have we in our spectroscopes and telescopes been watching the genesis of a nebula from a prior state of matter, which will perhaps in its turn be ultimately formed into a Sun and its attendant planets? Many problems then of intense interest are suggested by the new star in Auriga, and yet, although our knowledge of these rare and temporary appearances in the heavens has been vastly increased by its advent, we must fain confess that it has also accentuated our ignorance of the ways by which the Divine Intelligence works out His wonderful plans. What then are we to think of those who like Strauss and his followers in Germany, and their more recent English imitators, boasting of a knowledge of the formation of the universe which is not warranted by exact science, use it to attack the Mosaic account of the creation which is given in the first chapter of Genesis, on the interpretation of which theologians and exegetists are by no means agreed, and thence with rare philosophical acumen deduce that science and revelation are in antagonism the one with the other. "And God said; Be light made. And light was made." And although the Divine Wisdom is not limited by any possible ways we may conceive of for the first dawning of light in our system, yet perhaps the method selected was like to that which resulted in the appearance of the new star of 1892 in the outskirts of the Milky Way.

THE SOLAR CHROMOSPHERE IN 1891 AND 1892.*

WALTER SIDGREAVES.

The mean height of the chromosphere was notably above the annual average on June 9 and June 11 of 1891, and on June 3, Sept. 4, and October 22 of 1892.

Extensive elevations have been frequent during the past year, and have not been confined to any particular position with refer-

* *The Observatory*, March, 1893.

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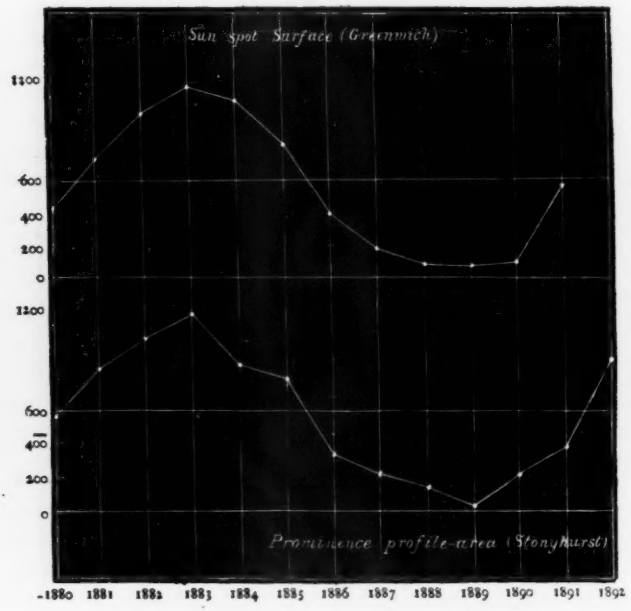
ence to the solar equator. The most remarkable of these were observed on June 3 and October 22. On June 3 the measures show an elevated region extending from 29° on the west side to 35° on the east side of the north pole, and another between 4° and 30° on the east side of the south pole. On October 22 four such regions were observed at mean latitudes 51° and 27° in the N.E. quadrant, at 20° in the S.E. quadrant, and at 79° in the S. W. quadrant, covering respectively 10°, 22°, 8° and 26°.



Referring to previous years we find that the last maximum period of the spot-cycle was also remarkable for the number and extent of these elevations of the chromosphere; and that the intervening minimum period was marked, in the opposite sense, by chromospheric depressions. It further appears, from the observers' notes, that during the maximum period of 1882-83 the chromosphere was on the whole brighter, and in the minimum year 1889 it was fainter than usual; and we have, at a date which may be very near the actual maximum, Nov. 30, 1882, the singular record of the C line doubly reversed on the chromosphere nearly all round the limb. We are now approaching a new maxi

mum, and in the past year the chromosphere has been growing in brightness.

Chromosphere in 1891.

	No. of days of observation.	Mean height of chromosphere excluding prominences	Mean height of prominences.	Mean extent of prominence in arc.	Highest prominence.
		"	"	° ′	"
January	1	8.54	17.09	2 0	17.09
February	5	8.03	31.52	17 53	111.07
March	0				
April	1	8.54	28.19	13 39	46.99
May	3	7.99	19.40	8 34	53.40
June	6	8.55	29.90	21 23	76.90
July	4	7.05	20.94	10 4	51.26
August	2	6.83	23.50	13 14	39.73
September	7	7.39	29.43	30 45	72.62
October	7	7.26	28.19	13 36	76.47
November	0				
December	2	8.12	30.33	15 42	102.11
Mean for ten months	3.8	7.83	25.85	14 41	64.76

Chromosphere in 1892.

	No. of days of observation.	Mean height of chromosphere excluding prominences	Mean height of prominences.	Mean extent of prominence in arc.	Highest prominence.
		"	"	° ′	"
January	6	7.69	31.27	22 43	66.64
February	6	8.20	27.98	22 46	64.93
March	7	7.43	33.32	18 34	158.49
April	5	7.43	27.25	22 38	58.96
May	8	7.65	31.82	23 31	88.86
June	9	7.89	28.32	39 17	76.90
July	7	8.24	24.35	30 1	62.37
August	2	8.33	25.42	35 35	46.99
September	2	8.54	28.41	41 49	106.80
October	4	8.54	27.89	42 27	64.08
November	2	7.69	32.46	42 43	93.98
December	6	7.60	27.55	27 49	93.98
Mean for the year	5.3	7.94	28.84	30 49	81.92

The annual means of the prominence-measures show that these have been increasing in number, height, and extent since 1889; and the accompanying curves show that the annual mean profile-areas of the prominences follow very closely those of the mean

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spot-areas. The profile-areas of the prominences are expressed in minutes of visual arc; but the scale unit has been made 3.7 times that of the comparison-curve, in order to bring the mean ordinates of the two curves to the same length. The spot-areas, expressed in millionths of the visible hemisphere, have been taken from the Greenwich observations, and those belonging to the unpublished volumes for 1890 and 1891 have been kindly supplied by the Astronomer Royal.

STONYHURST Observatory, Lancashire.

THE MODERN SPECTROSCOPE.

VII.

*The Spectroscope of the Royal Observatory, Edinburgh.**

L. BECKER.

The optical part of this instrument is the same as has been used at Dun Echt Observatory for several years. The Sun's rays, after reflection by the heliostat, fall on an object glass of 6 inches aperture and 7 feet focal length, which forms an image of the Sun on the slit attached to the collimator. By two endless cords the observer can correct the position of the heliostat without going outside the hut. The slit is formed by two plates of platinum with both jaws opening simultaneously by the motion of a screw. By a rack and pinion the slit can be brought into focus of the collimating lens. The latter has a free aperture of 4 inches and a focal length of four feet. Two feet in front of it the Rowland grating stands on the face plate of the recording apparatus. It is fixed in a brass frame with a T footpiece, with levelling screws at the ends. The Rowland grating—a present from the Johns Hopkins University at Baltimore to the Earl of Crawford's Observatory—contains 14,438 lines to every inch, ruled on speculum metal, its ruled surface being 5.5 by 3.5 inches. Although there is a slight difference in the focus of the spectra on either side of the normal, we are convinced that the irregularities in ruling which cause this defect have been without influence on this work. This is satisfactorily shown by the fact that close double lines which were separated by Professor Piazzi Smyth with similar optical appliances, were found to be double and well defined at Dun Echt. Moreover, a great number of faint lines, never recorded

* *Trans. Roy. Soc.* Edinburgh, vol. XXXVI, Part I, No. 6.

before, were observed on both sides of the normal of the grating, their reality being often abundantly established by their increased intensity in a low Sun.

The different rays are received by the 4-inch object-glass of the viewing telescope, of which the focal length is 4 ft. 11 in. There is a filar micrometer provided with two cross wires inclined 45° to the horizon. Their intersection serves as the zero point. An eye-piece, with a magnifying power of 120 diameters, was employed on all occasions. The viewing telescope forms an angle of 25° with the collimator. Each is supported on a separate concrete pier.

The recording apparatus consists of two distinct parts, one for magnifying the angular motion of the grating, and the other for recording the corresponding arc on a broad fillet of paper. The grating stands on a plate attached to the same vertical axis as a 6-inch worm-wheel (A) of 180 teeth. This wheel is turned by a tangent screw (*a*) on the end of a half-inch steel rod 12 inches in length, the other end carries a 12½-inch gun-metal wheel (B) with 150 teeth. The position of the rod can be adjusted so as to insure proper contact of the screw with the worm-wheel. A system of wheelwork turns the wheel B. The latter is geared into a 1¾-inch pinion (*b*) of 15 teeth, on the axis of which a second wheel (C) of 11½ inches diameter and 140 teeth gears with a second pinion (*c*) of the same dimensions as the first. The two horizontal axes of *b*, C, and *c* are clamped in the slot of an adjustable bracket. All these appliances are attached to a strong mahogany frame, 2 feet square by 2 feet high, provided with three foot screws, and carried by a massive concrete pier.

It is apparent that the angular motion of the second pinion (*c*) is

$$180 \times \frac{150}{15} \times \frac{140}{15}$$

equal to 16,800 times as large as that of the grating. By a long ⅜-inch iron rod the second pinion can be turned by the observer from the eye-end of the viewing telescope.

The rod, however, is not fixed immediately to the pinion, but transmits its angular motion by a very useful kind of joint, without communicating any longitudinal vibration. It is employed by Mr. L. Casella in his recording anemometers, and was introduced here at the suggestion of Dr. Copeland. Two square bars are screwed crosswise together, each of which fits exactly without tightness into a deep groove in a corresponding disk. The grooved surfaces of the disks face each other, and turn in parallel

planes, the only connection between them being the gliding cross. If the axes of rotation be parallel, although not necessarily in the same line, the transmission of rotary motion from one to the other is perfect. To prevent the cross from altering its plane of rotation one of its bars has a projecting plate which slides in narrow channels at the back of the groove of the corresponding disk. In our instrument one of the disks is carried by the second pinion (*c*), while the axis of the other is supported by the pillar of the viewing telescope, and is connected with the long iron rod by a Hooke's joint.

Underneath the eye-end of the viewing telescope, the other end of the iron bar is attached, by another Hooke's joint, to the axis of a wooden "recording" wheel. This wheel, which is 6¼ inches in diameter, rotates inside a narrow box in such a way that its rim, 2 inches in breadth, is level with the outside of the lid of the box. Above the exposed part of the recording wheel is a loaded swing frame carrying a roller of the full breadth of the wheel. Both wheel and roller are covered with sand paper, to insure a grip on the paper fillet which passes between them. A load of about five pounds is sufficient to prevent slipping. When observing, it is by turning this roller that the grating is moved. The paper, 1⅞ inch wide, is supplied from a large roll inside the box, and passes through a slit in the lid and over a flat surface to the wheels. On the lid, turning on a common axis, are five recording levers provided with prickers at their free ends. The prickers which form dots in a straight line across the fillet about ⅜ inch apart, are easily worked by the thumb and fingers of one hand, either singly or simultaneously. To this end the levers are suitably splayed at the fulcrum ends. The levers are smartly raised by springs as soon as the pressure is removed. Thirty-one different records can be made by the various combinations of the five needles, but only 19 have been employed. The full revolutions of the recording wheel are registered in a simple manner. A strong nail was driven into the rim of the wheel, and filed away to a sharp edge, which leaves a distinct mark on the paper every time it passes beneath the roller. These marks served as zero points in reading off the observations. We may mention that in the 3500 feet of paper that contains the observations, not one of these marks is wanting; and, judging from the intervals between them, the fillet has never once slipped. Apart from this safeguard the observer, when turning the roller, could always see in the viewing telescope that the grating had moved; and this could not possibly happen unless the fillet had correspondingly ad-

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vanced. If the recording wheel was intentionally held fast it was impossible to draw the fillet over it by turning the roller.

As to the linear distance between two lines on the paper, it may easily be computed from the figures given, that the D lines for intance are 19¾ inches apart, whilst the whole region from λ 6024 to 4861 would require a strip 314 feet long.

The apparatus works in the following manner:—The observer with his right hand turns a toothed wheel on the same axis as the roller; this drives the recording wheel and moves the paper along by friction. The long iron rod transmits this motion to the disk of the connecting joint, and then by means of the cross to the other disk which is fixed to the second pinion. This second pinion, acting through the wheels and endless screw, slowly rotates the grating, thus causing the lines of the spectrum to move across the field of view. When the line under observation coincides with the intersection of the wires, the fingers of the left hand depress one or more of the needles according to the degree of blackness of the line. If the lines of the spectrum are near together, they can be registered as quickly as the eye can appreciate their individual characteristics.

In spite of all the connections and the smallness of the worm-wheel, the probable error of one observation of the relative position of the grating is but ± 0″.77 of arc as computed from lines half-way between standard lines. This corresponds to $\frac{1}{9000}$ inch in the circumference of the worm-wheel.

For effecting a quick motion of the grating, the bracket to which the wheelwork is fastened turns round a pivot at the upper end, and can be raised out of position by a string. By a long wooden handle the observer can then rotate the tangent-screw directly, without quitting his seat at the eye-end of the viewing telescope.

The instrument could be much simplified. A small table moving easily round a vertical axis from which a rigid arm projects as far as its rigidity permits, and of course balanced, and a screw of low pitch acting on the arm similarly to the slow motion of a transit-circle in declination, would be a simple substitute for all our multiplying gear.

When a great number of lines have to be determined by eye-observations, such an instrument will always give accurate results in a comparatively short time, provided it is possible to introduce a sufficient number of standard lines.

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STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

A recent examination of photographs of stellar spectra taken at Cambridge, and at Arequipa, has resulted in the discovery of several interesting objects which are enumerated in the following table. The designation of the star is given in the first column and is followed by its approximate right ascension and declination for 1900, its magnitude, and a brief description of its photographic spectrum.

Designation.	R. A. 1900		Dec. 1900		Magn.	Description.
	h	m	°			
B. D. + 49° 41	0	12.2	+ 49	44	9.4	Type IV.
B. D. — 13° 893	4	24.5	— 13	17	5.8	F line bright.
A. G. C. 5429	4	43.8	— 36	23	7½	Type IV.
A. G. C. 11890	8	42.4	— 29	21	7½	Type IV. [bright).
— —	15	27.0	— 71	32	—	Type III (Hydrogen lines
A. G. C. 22838	16	47.9	— 44	50	8.2	Type V (Bright lines).
Z. C. XVIII^h 56	18	3.3	— 63	38	9½	Type III (Hydrogen lines
A. G. C. 26129	18	59.7	— 38	17	8½	Type IV? [bright).
B. D. — 21° 6376	23	6.3	— 21	32	9.0	Type IV.

A. G. C. 11890 was found by Mr. A. E. Douglass in an examination of the photographs taken in Peru before they were sent to Cambridge. This object is probably identical with No. 29 of the list published in the *Astronomische Nachrichten*, Vol. XCIX, 337, which is there erroneously announced as U. A. Pyxis, 34, magnitude 6.5. The spectrum of the latter star is of the second type.

The star of the ninth magnitude whose approximate position for 1900 is in R. A. 15^h 27.0^m, Dec. — 71° 32′ has a spectrum similar to that of variable stars of long period. The photographic charts of this region show a slight variation but the material is not sufficient to regard the variability as confirmed.

A.G.C. 22838 has a spectrum similar to that of the bright line stars in Cygnus and increases the known number of these objects to fifty-one. Its galactic longitude is — 2° 7′ and its galactic latitude is 308° 47′.

Z.C. XVIII^h 56 has a spectrum similar to other known variables of long period. Photographic charts of this region were therefore examined and resulted in the confirmation of variability of this star. Measurements of photographs, taken on August 8, August 13, August 20, September 4, 1889; June 12, June 12, 1891, and September 17, 1892, gave for it the photographic magnitudes 8.1, 8.1, 8.1, 9.0, 7.6, 7.6 and 7.9.

* Communicated by Edward C. Pickering, Director of Harvard College Observatory.

Photographs have also been obtained of the spectra of U Virginis, V Boötis, S Geminorum, T Cassiopeiæ, R Piscis Austrini, and T Geminorum, which show them to be of the third type having the hydrogen lines bright. The photographic spectrum of the variable star of the fourth type, R Leporis, has also been obtained.

HARVARD COLLEGE OBSERVATORY,
May 10, 1893.

ON THE GEOMETRICAL CONSTRUCTION OF THE OXYGEN ABSORPTION LINES GREAT A, GREAT B, AND α OF THE SOLAR SPECTRUM. *

GEORGE HIGGS.

In the early part of August, 1890, the photographic work of the normal solar spectrum which I had undertaken had been carried as far as great A, or the limit of visibility in the red, and to λ 8350, or beyond *z* in the invisible regions.

During the two previous months of continuously dull weather, while classifying and comparing results, I was interested, on making a close examination of the head portion of the A line, to find the symmetrical construction, the rythmical grouping, the harmonic order of sequence, and other characteristics of the B line repeated here in every detail.

These two bands, together with alpha, are composed of a number of doublets or pairs, which approach each other on the more refrangible side with uninterrupted regularity, finally crossing, and at the limiting edges of all three bands the three last pairs overlap each other.

The differences of wave-length between the components of pairs increase in the same order.

These and other properties, which will be referred to, are still more obvious in the trains or flutings.

From its holding an intermediate rank in each of its distinguishing characters I was induced to adopt B as a typical group in a geometrical representation, and to investigate the subject by means of rectangular co-ordinates.

Before a complete analysis could be made out, a micrometer had to be completed. This consisted of a platform, serving as a plate holder, which was made to travel on runners between par-

* Communicated by the author. Read before the Royal Society.

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allel ways by means of a screw of such a pitch as to move the negative from one division of the scale to the next, for one revolution of the divided plate on the screw head, this latter being divided into 100 parts.

On and over the platform, a microscope is mounted with slide motions at right angles to each other; an index of glass fibre and reflector complete the apparatus.

Over 1000 measurements of nearly two hundred lines have been made, 100 of which belong to great A.

In the analysis the axis of x is assumed to occupy a position coincident with, or parallel to, the scale of $1/10^{10}$ m. units, and the positions of the various lines are set off on this scale (see fig. 1) for the group, which is divided into four series. Ordinates are then drawn in the position occupied by each line. The axis of y is divided into a number of equal parts, 1, 2, 3, n. Lines parallel to the axis of x, drawn from each of these divisions, intersect the respective ordinates. The continuous curve passing through the points of intersection is found to possess all the properties of a parabola.

Three points at least are selected to determine the position of the vertex and value of latus rectum. The distance from the origin along y is also found for an ordinate to the first line of a series.

Now, from the equation to the parabola $y^2 = px$, the formula $\lambda = \mathrm{V} + \frac{(n+c)^2}{p}$ is derived, where V = the wave-length in $1/10^{10}$ m. units of a point in the spectrum coinciding with the vertex of the curve; p, the latus rectum; n, any number of units, reckoning from the origin; c, a constant.

In practice a representation more suitable for lantern projection being desirable, two units are taken on y for each line of the series; the equation then becomes

$$\lambda = \mathrm{V} + \frac{(2n+c)^2}{\mathrm{L}},$$

where $\mathrm{L} = 4p$, and c has twice its former value.

The computed places in the tables are derived from the equation in the latter form; the maximum want of agreement between these and the observed positions not exceeding (for α and B) 0.015 tenth-metre.

In the case of A the agreement is not quite so close, the maximum difference being about 0.05 tenth-metre.

It might be supposed that the greater difference arose from un-

certainties of observation, caused by the greater haziness and breadth of the lines composing the A group; but it so happens that each component is in itself so much of a double as to show a bright rift in the centre, which facilitates the centralisation in some degree.

The differences referred to are attributable to the fact that the curve for any series in A, B, or α is not rigorously parabolic, but one which cuts the parabola in three points, similar to the curve of sines, cutting a straight line and terminating in the same phase as at the origin. This difference is so extremely minute in B (and in α still less) that it would require a representation more than 10 feet square, or a good sized lantern screen, to show two separate tracings at a point of maximum divergence, assuming the tracings to have but a breadth of 1/100th of an inch.

Following the stronger doublets in the fluting or train of A on the less refrangible side, is a secondary train of thinner, sharply defined, doublets, which, with a solar altitude of about 10°, may be traced on the photographic prints to about the 12th position. This series, which was not previously known to exist, conforms to the same formula, and in the table of wave-lengths is denominated the "Secondary Train of A." This secondary train follows in the wake of the right component of the primary series. In the head, however, similar secondary groups follow in the wake of both right and left components, overlapping and interlacing each other in such a manner that their resolution into series can only be arrived at by deductive processes; the difficulty is increased by the fact that a large number of positions are occupied by the dense lines of the main band.

These two series will be referred to as "Sub-groups" in the head of A. They are, with two or three exceptions, given in a fragmentary state. At the same time, there is nothing to prevent their hypothetical positions being carried further, except that the greater density of the principal series precludes the possibility of obtaining any check in regard to their conformity.

Generally, a couple of numbers of the head bands are common to two separate series; this arises from their complexity being suggested by the nature of the analysis, and, as a matter of fact, some of these have been observed as doubles by Professor Rowland, of Baltimore.

In all cases of this kind a greater density is observable on the prints, and is doubtless the cause of the extra density of 7608.83, which belongs to two sub-groups; the line 7610.10 is known to be a double, but cannot with safety be measured as such.

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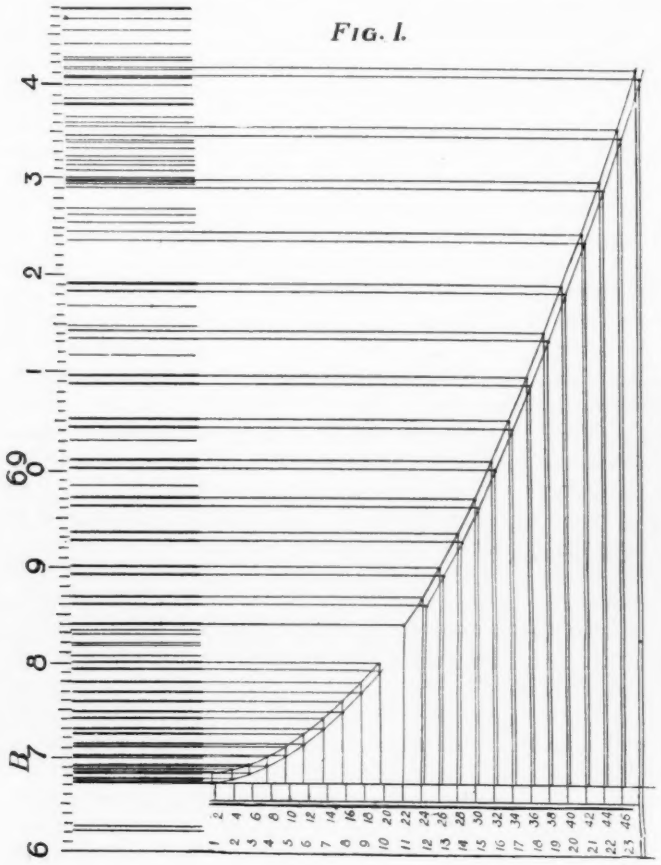
Owing to their incompleteness, the elements of the curves for the sub-groups in head of A have not been made out, but a glance at their second differences is sufficient to establish their agreement with the preceding form, since an interval is equal to $d' + (n-1)\,d''$, where d' and d'' are first and second differences, and n any interval from the commencement of the series.

Fig. I.



Note.—Since writing the above I find that Mr. Johnstone Stoney has written a note which was published with a paper by Dr. Huggins on the spectrum of hydrogen, in which he refers to the conditions under which members of a harmonic series might fall near to, but not on, a curve.

Fig. 2 is an enlargement of part of A.

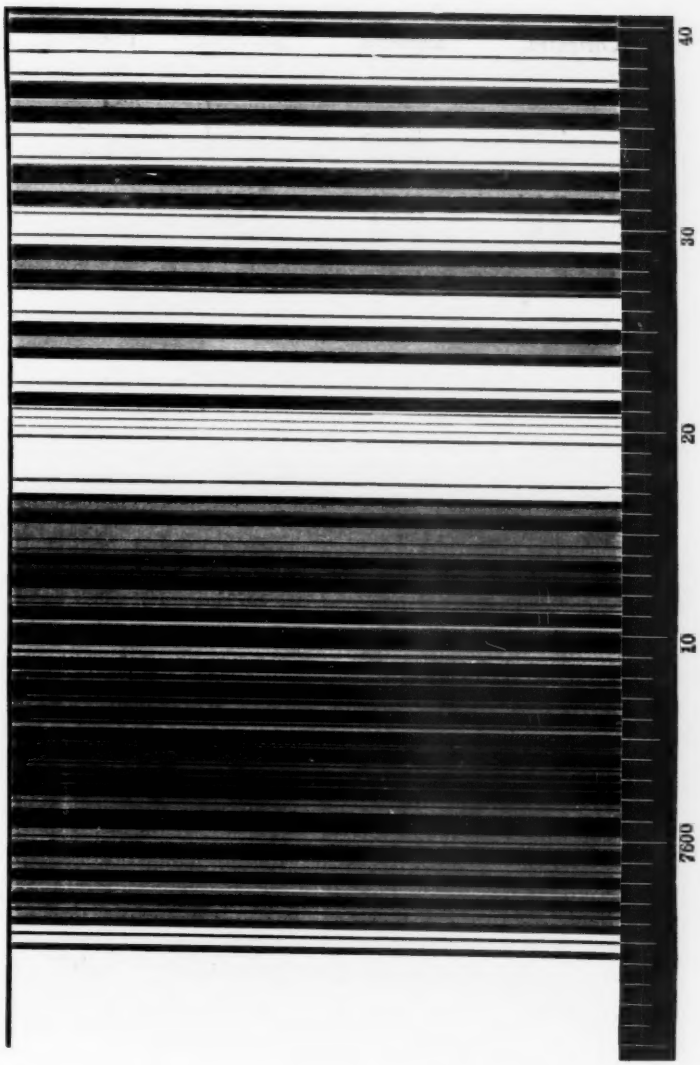


FIG. 2.

Head of the Alpha Line.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	6276.792	6276.798	6277.652	6277.644
2.	77.020	77.013	77.845	77.856
3.	77.514	77.518	78.190 78.280 78.370	78.335
4.	78.275	78.190 78.280 78.370	79.084	79.082
5.	79.302	79.302	80.095	80.095
6.	80.596	80.594	81.374	81.375
7.	82.156	82.148	82.924	82.922
8.	83.983	83.990	84.735	84.736
	V = 6276.775		V = 6277.632	
	L = 30.019		L = 29.964	
	$c = -$ 1.29		$c = -$ 1.41	

Train of the Alpha Line.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
9.	...	...	6287.935	6287.942
10.	6289.596	6289.591	90.411	90.408
11.	92.344	92.350	93.140	93.141
12.	95.356	95.360	96.141	96.140
13.	98.634	98.640	99.416	99.407
14.	6302.176	6302.178	6302.941	6302.940
15.	05.984	05.980	06.741	06.740
16.	10.056	10.040	10.795	10.806
17.	14.394	14.399	15.135	15.140
18.	18.996	19.008	19.750	19.740
	V = 6276.693		V = 6277.746	
	L = 30.19		L = 29.985	
	$c = -$ 0.263		$c = -$ 0.515	

Head of Great B.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	6867.464	6867.455	6868.457	6868.464
2.	67.776	67.788	68.782	68.771
3.	68.338	68.337	69.330	69.326
4.	69.150	69.148	70.130	70.130
5.	70.212	70.220	71.180	71.182
6.	71.523	71.530	72.485	72.484
7.	73.084	73.080	74.039	74.033
8.	74.895	74.892	75.834	75.831
9.	76.955	76.950	77.879	77.877
10.	79.266	79.274	80.170	80.172
	V = 6867.394		V = 6868.397	
	L = 32.03		L = 32.194	
	$c = -$ 0.5		$c = -$ 0.53	

Train of Great B.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
11.	...	...	6884.077	6884.090
12.	6886.012	6886.000	86.998	86.990
13.	89.181	89.182	90.140	90.142
14.	92.601	92.615	93.560	93.545
15.	96.271	96.277	97.200	97.201
16.	6900.192	6900.193	6901.120	6901.108
17.	04.364	04.368	05.264	05.267
18.	08.786	08.786	09.680	09.678
19.	13.458	13.444	14.334	14.340
20.	18.382	18.367	19.245	19.255
21.	23.555	23.545	24.412	24.421
22.	28.980	28.980	29.840	29.839
23.	34.655	34.662	35.518	35.509
24.	40.580	40.580	41.430	41.431

V = 6867.529	V = 6868.812
L = 31.922	L = 31.767
c = + 0.29	*c* = + 0.03

Head of Great A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	7593.980	7593.98	7595.26	7595.260
2.	94.276	94.28	95.42 95.54 95.66	95.543
3.	94.796	94.79	96.05	96.050
4.	95.540	95.42 95.54 95.66	96.78	96.781
5.	96.508	96.49	97.73	97.736
6.	97.700	97.69	98.90	98.915
7.	99.116	99.12	7600.29	7600.318
8.	7600.756	7600.80	01.96	01.945
9.	02.620	02.64	03.77	03.796
10.	04.708	04.74	05.90	05.871
11.	07.020	07.03	08.21	08.170
12.	09.556	09.54	10.71	10.693
13.	12.316	12.31	13.44	13.440
14.	15.300	15.30	16.39	16.411

V = 7593.904	V = 7595.195
L = 35.714	L = 35.715
c = − 0.357	*c* = − 0.473

Train of Great A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
15.	...	...	7621.260	7621.299
16.	7623.590	7623.535	24.765	24.772
17.	27.310	27.310	28.480	28.480
18.	31.255	31.275	32.445	32.413
19.	35.425	35.460	36.59	36.571
20.	39.820	39.840	40.97	40.954
21.	44.440	44.470	45.57	45.562

TRAIN OF GREAT A, *Continued.*

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
22.	49.285	49.305	50.39	50.395
23.	54.355	54.360	55.448	55.453
24.	59.650	59.615	60.715	60.736
25.	65.170	65.148	66.218	66.244
26.	70.915	70.880	71.945	71.977
27.	76.885	76.840	77.89	77.935
28.	83.080	83.025	84.075	84.118
29.	89.500	89.450	90.49	90.526
30.	96.145	96.105	97.13	97.159
31.	7703.015	7703.020	7704.02	04.017
32.	10.110	10.160	11.16	11.100

V = 7594.669	V = 7596.044
L = 35.556	L = 35.556
c = + 0.067	c = − 0.04

SECONDARY TRAIN OF GREAT A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
15.	7622.076	7622.06	...	7623.290
16.	25.613	25.62	7626.79	26.790
17.	29.356	29.36	30.50	30.502
18.	33.305	39.29	34.42	34.426
19.	37.460	37.46	38.57	38.560
20.	41.821	41.81	42.91	42.910
21.	46.388	46.36	47.46	47.470
22.	51.161	51.19	52.24	52.242
23.	56.140	56.14	57.23	57.226

V = 7593.4535	V = 7596.122
L = 38.835	L = 37.736
c = + 3.34	c = + 2.019

Sub-group in Head of A following the 1st Series.

MEASUREMENTS ONLY.

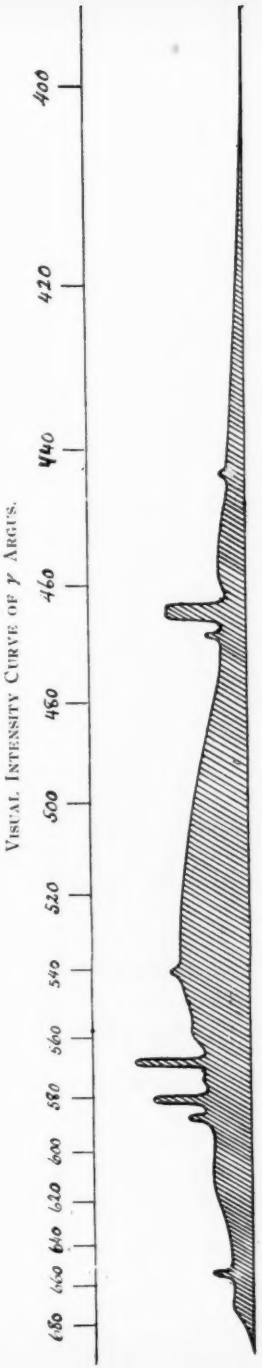
	Sub-series No. 1.	Sub-series No. 2.
5.	7597.00	7598.20*
6.	98.29	99.45
7.	99.74	7600.90*
8.	7601.42	02.57*
9.	03.25	04.40
10.	05.36	06.48
11.	07.65	08.83
12.	10.10*d*	11.28
13.	12.84	13.98
14.	15.78	...

Fragment of Sub-group in Head of A following the 2nd Series.

MEASUREMENTS ONLY.

	Sub-series No. 3.	Sub-series No. 4.
10.	7606.48	
11.	08.83	7610.10*d*
12.	11.45	
13.	14.28	
14.	17.25?	

The numbers marked with an * are hypothetical positions.



THE SPECTRUM OF γ ARGUS.*

W. W. CAMPBELL.

I have recently undertaken to determine as accurately as possible the positions of the bright lines in the spectra of some of the *Wolf-Rayet* stars. Fifty stars of that type are now known, of which γ Argus, of the 3d magnitude, is the only bright one. When this star is on the meridian of Mt. Hamilton its altitude is less than 6°, and can be observed with the great telescope only a few minutes each evening. Nevertheless I have been able to determine the positions of ten bright lines and bands by visual observations, with as great accuracy as the unfavorable position of the star will permit. The character of the lines is shown in the accompanying intensity curve, and their measured wave-lengths (Rowland's scale) are given in the following table. The continuous spectrum is visible from B to K, being particularly strong in the blue and violet.

The broad band 4651 is strongly suspected to be double with components near 4643 and 4659.

The extremely unfavorable weather prevented me from completing the investigation of the photographic portion of the spectrum, but a few partially successful photographs were obtained. They show many additional bright and dark lines, prominent among which are the bright line at λ 4469 (possibly the chromosphere line at λ 4472), the broad bright lines at λ 433 and λ 427, and *the dark lines* Hγ, Hδ and H. At F the spectrum appears to be strictly continuous. The visual observations show C to be bright.

* Communicated by the author.
† Hasty measures, half weight.

Li	1893 Feb. 15	Feb. 17.	Feb. 18.	Feb. 19.	Feb. 20.	Feb. 22.	Feb. 23.	Feb. 27.	Mch. 27.	Means.
	670				673		673			672
C	6563.1				6563.8		6567.1			6565
D_3	5875.8	5873.5	5872.1					5874.9	5874.6	5874
	5814.1	5813.8	5812.9					5809*	5812.5	5813
	5694.7	5695.1	5692.8					5693*	5695.7	5694
								5596		5596
								5412		5412
				4689.6	4689.0	4689.0		4688.0	4688.0	4689
				4651.4	4650.6	4651.2		4650.2	4649.2	4651
							4440.2	4441.4	4441.6	4441

A fuller discussion of this interesting spectrum, first observed by Respighi at Madras in 1871, is reserved for a future paper based upon more data. But I will point out that the wave-lengths of the principal lines assumed by Professor Lockyer* are radically different from those obtained by me.

MT. HAMILTON, May 8, 1893.

COMPARISON OF THE INTERNATIONAL METRE WITH THE WAVE-LENGTH OF THE LIGHT OF CADMIUM.†

ALBERT A. MICHELSON.

The measurement of luminous wave-lengths in metric values necessitates two distinct operations: the first is the determination of the order of interference produced by a source as nearly homogeneous as possible between rays reflected by two parallel planes; the second is the comparison of the distance between the planes with the metre.

In order to apply this method it is necessary in the first place to produce interference of a very high order and, in the second place, to regulate the position of the surfaces with such exactness that their distance, even when very great, may be determined with an approximation of a few millionths of a millimetre, and that their parallelism may be verified within a small fraction of a second.

A preliminary study of the radiations emitted by twenty different sources has shown that very few exist of such homogeneity that their wave-lengths can be used as absolute standards of length.

Most of the sources which correspond to the bright lines of the

* *The Meteoric Hypothesis*, pp. 389-391.
† *Comptes rendus*, 17 April, 1893.

spectrum are double, triple or of still more complex constitution; the radiations emitted by the vapor of cadmium, however, seem to be simple enough to conform with the best conditions.

In all cases when the vapors are produced at atmospheric pressure, the difference of path of the interfering rays cannot be carried beyond 2 or 3 centimetres, or 40,000 and 60,000 wave-lengths. These figures are very nearly the same as those found by M. Fizeau in his celebrated experiments on interference at great difference of path with sodium light.

If the lack of homogeneity of the source which this limit discloses is due to frequent collisions of the vibrating molecules among themselves or with those of the surrounding gas, which prevent them from executing freely their natural vibrations, it should be possible to greatly augment the order of interference by placing the luminous body in a vacuum, in order to diminish the number of collisions.

Thanks to this arrangement, it has been possible to obtain with a mercury line interferences corresponding to a difference of path of about half a metre, or 850,000 wave-lengths. An examination of the variations in the sharpness of the fringes, as the difference of path increases, shows however that the source is still very complex: it always appears single with the greatest dispersion that it is possible to realize*, while in reality it contains at least six distinct components.†

An examination of the light of cadmium vapor, made from this point of view, shows that the red line ($\lambda = 0\mu.6439$) is almost ideally simple, although a little wider than the components of the green line of mercury. The sharpness of the fringes diminishes according to an exponential law and disappears when the difference of path approaches 25 cm. or 400,000 wave-lengths; for a difference of 10 cm., the visibility is about 0.60 of its maximum value. Cadmium gives in addition three other remarkable lines, green, blue and violet; the first two are similarly very simple and give fringes almost as easily visible as those of the red line.

We have thus, for a single substance, three kinds of radiations

* A good grating, observed with care, permits a faint companion to be distinguished very near the principal line.

† The method which allows this result to be reached is based on the relation which exists between the distribution of the light of the source and the *visibility curve* of the fringes. The visibility V is given by the equation

$$V_2 = \frac{[\int \varphi(x) \cos 2\pi D x dx]^2 + [\int \varphi(x) \sin 2\pi D x dx]^2}{[\int \varphi(x)\, dx]^2}$$

in which $\varphi(x)$ represents the law of distribution of light in the source and D the difference of path.

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which may be examined successively without modifying the arrangement of the apparatus; the concordance of the results which they give for each increase of distance is a very important check on the exactness of the measures.

The apparatus employed to observe these interference phenomena serves at the same time for the comparison of the intermediate standards among themselves and with the metre; it may be called the *interferential comparator*. The essential part of this instrument is composed of a plate of glass with optically plane and parallel faces and two plane mirrors. The light which it is desired to examine falls on a plate of glass, the first surface of which is thinly silvered, at any incidence—ordinarily at 45°. The incident pencil divides into two parts, one reflected and the other transmitted. The reflected pencil is returned by one of the mirrors and again passes through the glass plate; the other is returned by the second mirror, reflects on the plate and finally is sent in the same direction. Elementary considerations show that this arrangement is equivalent to the superposition of two pencils, one reflected on the first mirror, the other on the imeag of the second with respect to the mirror. If the distance between these two plane surfaces, one of them real and the other virtual, is very small, white light may be employed; colored fringes are then observed, analogous to Newton's rings and situated on the surfaces themselves. If, on the contrary, the distance is many wave-lengths, it is necessary to employ monochromatic light.

It will suffice to examine the case in which the surfaces are absolutely plane and parallel. It is easy to see that the fringes are then concentric rings; they may thus be observed with the eye or in the principal focal plane of a telescope. Consequently, if one can succeed in maintaining the absolute parallelism of the surfaces during their motion, the fringes are always distinct, even though the source have a considerable apparent area.

The only difficulty is to determine the order of interference. This difficulty may be overcome by a stroboscopic method based on the periodicity of the induction sparks which produce the illumination of the vapors, the period of which (by a mechanism easy to construct) contains an exact and very considerable number of alternate maxima and minima of the passing fringes.

There is another method which seems to me more certain, and which has already been put in practice in the preliminary experiments made by myself in collaboration with Professor Morley; this is to employ several standards of intermediate lengths, each of which is approximately double the preceding. These stand-

dards are compared among themselves in a very exact manner by correcting by direct observation at each operation, the fraction of a fringe which exceeds a whole number. The exactness of this comparison is, moreover, controlled by the concordance of the results obtained with the three different radiations. We thus succeed in finding without error the number of fringes and the remaining fraction which corresponds to a distance of 10 cm. between the surfaces under known conditions of temperature and pressure.

The comparison of the final 10 cm. standard with the metre is made by moving this standard a distance equal to its own length, an operation which is repeated ten times; the position and inclination of the surfaces is controlled at each step by observation of the interference fringes with white light.*

At the first and last positions a mark on the standard is compared with the two marks on the normal metre by means of micrometer microscopes.†

The International Committee of Weights and Measures has done me the honor to invite me to repeat these experiments in the manner here indicated at the Pavillon de Breteuil. The necessary instruments, constructed in America for this purpose, were brought to Paris last July.

Preliminary investigations and the adjustment of the various instruments occupied all our time until the last of October, when the regular measures were commenced. The observations were at first made simultaneously by M. Benoît, Director of the International Bureau, and myself; but M. Benoît had a serious illness at the end of the first series and I have since been deprived of his valuable aid.

I am happy to take this occasion to thank him for all the facilities which he has kindly placed at my disposal and for the interest which he has taken in this work. I have at the same time received valuable assistance from MM. Chappuis and Guillaume, in the latter part of the work, and from Mr. F. L. O. Wadsworth, in the construction and installation of the instruments; I take pleasure in expressing to them my sincere thanks.

The two series of observations which I have been able to com-

* This method of producing *optical contact* offers the advantage that the position and inclination of one of the surfaces may be controlled by the interferences given by the virtual image of the other. There is no danger of displacing the apparatus during the observations. It is also possible to attain absolute contact, which is impossible with real surfaces, and to pass this position in either direction at pleasure.

† In the present experiments this comparison has been made with an auxiliary metre, which in its turn was compared directly with the normal metre.

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plete are not yet entirely reduced; but an approximate calculation shows that there does not exist between them a difference of a wave-length in the total distance between the two extreme marks of the standard metre, which corresponds to an error of about $\frac{1}{1500000}$.*

We have thus a means of comparing the fundamental base of the metric system with a natural unit with the same degree of approximation as that which obtains in the comparison of two standard metres. This natural unit depends only on the properties of the vibrating atoms and of the universal ether; it is thus, in all probability, one of the most constant dimensions in all nature.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Total Eclipse of April 16.—We learn from *Nature* of April 27 that the following telegram has been received by Lord Kelvin from Professor Thorpe, who is in charge of the English eclipse party in Africa:— "April 19, 1893, Thorpe to President Royal Society, Burlington House, London. Eclipse successfully observed at Fundium. Position good, weather fine, very slight haze. Slit spectroscope good, but mainly prominence lines; calcium and hydrogen seen projected on Moon. Thirty prismatic camera photographs, eighteen excellent; mainly prominence lines; corona lines doubtful. Ten coronograph pictures, six very good. Photometric work successful; twenty comparisons with equatorial, eleven with integrating apparatus. Deslandres and Colculesco also observed at Fundium, with good results. No word from Bigourdan at Joal. Health of expedition good. Blonde leaves for Teneriffe to-morrow.—Thorpe."

The Editor—Astronomy and Astro-Physics—DEAR SIR: In my paper in the December No. of ASTRO-PHYSICS—a note on the new spectrum of Nova Aurigæ p., 883, line 2, the figure 155 $\mu\mu$ is wrongly attributed to Dr. Crew's measurements. The interval has apparently been taken by mistake from the Stonyhurst list, instead of from the observations made at Mount Hamilton. If you will kindly give a prominent place in your next No. to this apology for an unaccountable error, you will greatly oblige the author. WALTER SIDGREAVES.

Circular Concerning the Hodgkins Fund Prizes. In Oct., 1891, Thomas George Hodgkins, Esq., of Setauket, New York, made a donation to the Smithsonian Institution, the income from a part of which was to be devoted "to the increase and diffusion of more exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man."

* In the determination of the relative values of the three wave-lengths, the error is only about $\frac{1}{20000000}$.

With the intent of furthering the donor's wishes, the Smithsonian Institution now announces the following prizes to be awarded on or after July 1, 1894, should satisfactory papers be offered in competition:—

1. A prize of $10,000 for a treatise embodying some new and important discovery in regard to the nature or properties of atmospheric air. These properties may be considered in their bearing upon any or all of the sciences—*e. g.*, not only in regard to Meteorology, but in connection with hygiene, or with any department whatever of biological or physical knowledge.

2. A prize of $2,000 for the most satisfactory essay upon—

(*a*). The known properties of atmospheric air considered in their relationship to research in every department of natural science, and the importance of a study of the atmosphere considered in view of these relationships.

(*b*). The proper direction of future research in connection with the imperfections of our knowledge of atmospheric air, and of the connections of that knowledge with other sciences.

The essay, as a whole, should tend to indicate the path best calculated to lead to worthy results in connection with the future administration of the Hodgkins foundation.

3. A prize of $1,000 for the best popular treatise upon atmospheric air, its properties and relationships (including those to hygiene, physical and mental).

This essay need not exceed 20,000 words in length; it should be written in simple language, and be suitable for publication for popular instruction.

4. A medal will be established, under the name of THE HODGKINS MEDAL OF THE SMITHSONIAN INSTITUTION, which will be awarded annually or biennially, for important contributions to our knowledge of the nature and properties of atmospheric air, or for practical applications of our existing knowledge of them to the welfare of man-kind. This medal will be of gold and will be accompanied by a duplicate impression in silver or bronze.

The treatises may be written in English, French, German or Italian, and should be sent to the Secretary of the Smithsonian Institution, Washington, before July 1, 1894, except those in competition for the first prize, the sending of which may be delayed until December 31, 1894.

The papers will be examined, and prizes awarded, by a committee to be appointed as follows: One member by the Secretary of the Smithsonian Institution, one member by the President of the National Academy of Sciences, one by the President, *pro tempore*, of the American Association for the Advancement of Science; and the committee will act together with the Secretary of the Smithsonian Institution as member, *ex officio*. The right is reserved to award no prize, if, in the judgment of the committee, no contribution is offered of sufficient merit to warrant an award. An advisory committee of not more than three European men of science may be added at the discretion of the Committee of Award.

If no disposition be made of the first prize at the time now announced, the Institution may continue it until a later date, should it be made evident that important investigations relative to its object are in progress, the results of which it is intended to offer in competition for the prize. The Smithsonian Institution reserves the right to limit or modify the conditions for this prize after December 1, 1894, should it be found necessary. Should any of the minor prizes not be awarded to papers sent in before July 1, 1894, the said prizes will be withdrawn from competition.

A principal motive for offering these prizes is to call attention to the Hodgkins' fund, and the purposes for which it exists, and accordingly this circular is sent to the principal universities and to all learned societies known to the Institu-

tion, as well as to representative men of science in every nation. Suggestions and recommendations in regard to the most effective application of this fund are invited.

It is probable that special grants of money may be made to specialists engaged in original investigation upon atmospheric air and its properties. Applications for grants of this nature should have the endorsement of some recognized academy of sciences, or other institution of learning, and should be accompanied by evidences of the capacity of the applicant, in the form at least of one memoir already published by him, based upon original investigation.

To prevent misapprehension of the founders wishes, it is repeated that the discoveries or applications proper to be brought to the consideration of the Committee of Award, may be in the field of any science or any art without restriction; provided only that they have to do with "the nature and properties of atmospheric air in connection with the welfare of man."

Information of any kind desired by persons intending to become competitors will be furnished on application.

All communications in regard to the Hodgkins Fund, the Hodgkins Prizes, the Hodgkins Medals, and the Hodgkins Fund Publications, or applications for grants of money, should be addressed to S. P. Langley, Secretary of the Smithsonian Institution, Washington, U. S. A.

S. P. LANGLEY, *Secretary of the Smithsonian Institution.*

Washington, March 31, 1893.

"Asymmetry" of the Concave Gratings.—Dr. Ames writes us that the so called asymmetry of a concave grating noticed by Dr. Rydberg in a recent number of the *Philosophical Magazine* and in the last number of this journal, is a peculiarity very often observed in the gratings used and tested in the Physical Laboratory of the Johns Hopkins University. The cause is beyond a doubt due to a slight error made in placing the surface to be ruled under the diamond point. In Professor Rowland's new dividing engine, which is approaching completion, this error will be entirely avoided. In Dr. Ames' paper on the Concave Grating, reference is made to the proper correction for this fault, viz., revolution around a vertical axis. Dr. Rydberg's theory is thus confirmed in every point.

Selective Absorption of Gratings.—In a recent paper by F. Paschen on "Bolometric Investigations," (*Wied. Ann.*, No. 2, 1893), the question of the selective absorption of gratings is for the first time considered. The author finds as the result of a series of most careful experiments that the energy-curves of different gratings have individual peculiarities, depending upon the shape of the groove cut by the diamond point. These peculiarities are such as to render the results obtained with different gratings entirely uncomparable, and to preclude the possibility of using a grating, either metallic or glass, for absolute measurements of intensity.

This dependence of the shape of the energy curve upon the form of groove of the grating is entirely in accordance with the theory of gratings, as given recently in this magazine by Professor Rowland.

Separation and Striation of Rarefied Gases.—In the *Philosophical Magazine* for March, 1893, Mr. E. C. C. Baly gives the results of some most interesting and ingenious experiments performed upon the electric discharge through gases. He finds that when the current is passed through a mixture of two gases, the components are separated, one collecting at the negative pole, the other remaining

behind; and conjectures that this fact may be intimately connected with the differences observed in the spectra of the positive and negative poles. His experiments also lead him to think that with a pure gas or vapor there is no striation, a most suggestive idea.

Absorption Spectrum of Oxygen.—In his study of these lines in the so-called "solar spectrum" which are caused by the absorption of the Earth's atmosphere Mr. L. E. Jewell has found another series besides the A, B, and α groups which are due to oxygen. This new one is in the region about w. l. 5790. All four series are of marvellous similarity; and there is a most evident law connecting the series as well as the lines of each series. Mr. Jewell is at present engaged in working out these relationships in full.

Correction to Professor Rowland's New Table of Standard Wave-lengths.—A. & A.-P., April, 1893, p. 337. Last line on page, for 0.050 read 0.150.

Observations of the Aurora.—Lieutenant Peary of the United States Navy, during his coming expedition to the northern-most Greenland, will record observations of the aurora, upon a plan that will enable comparisons to be made in detail with records from other localities. The plan is already in operation, upon an international basis, and the results are proving to be important. Numerous observers widely distributed are desirable, and inasmuch as even those who have no special technical knowledge may make entries that will be of value, any who feel so disposed may co-operate. Further information and supplies of blanks may be obtained from the undersigned, who will be glad to receive also any records of observations of the aurora whatever, for purposes of comparison.

M. A. VEEDER.

Lyons, New York, U. S. A., April, 1893.

A New Astro-Photometric Method.—Under this title Messrs. Lagrange and Stroobant describe a form of Stellar photometer which they have invented, and to some extent tested by observation at the Royal Observatory at Brussels. The principal novelty seems to be the employment of an incandescent electric lamp as the source of light for an artificial comparison star, and the control of its brightness by measuring with electrical apparatus the intensity of the current used. Within the ordinary limits of variation the intensity of the light was found by an independent investigation to be nearly a linear function of the electromotive force. The brightness of the artificial star is varied (1) by means of an iris diaphragm, (2) by introducing in the path of the rays a variable thickness of glass, for which purpose two opposed glass wedges can be moved in and out by the observer. For observing colored stars a strip of glass of the proper shade is placed in front of the electric lamp, but it would seem as if this were only shifting the difficulty attending such comparisons to a subsequent investigation, liable to the same errors.

The introduction to Messrs. Lagrange and Stroobant's paper (Bulletin de l'Académie royale de Belgique, XXIII, No. 6) gives an excellent résumé of previous instruments for determining stellar magnitudes.

The Motion of the Solar System, from the Potsdam Observations.—Dr. P. Kempf of the Astro-Physical Observatory of Potsdam, has deduced the amount and direction of the motion of the solar system from Professor Vogel's measures of the motions of stars in the line of sight. As only 51 stars were bright enough for

observation the result of Dr. Kempf's reduction is necessarily subject to much uncertainty, but it is nevertheless of extreme interest from the fact that it is the only one based on spectroscopic methods which has yet been obtained. Two methods of reduction were employed. Giving all the stars the same weight, and regarding them as perfectly independent, the apex of the Sun's way is found to be in R. A. 206°.1 ± 12°.0, Dec. + 45°.9 ± 9°.2, and the velocity of the Sun's motion 11.6 ± 1.8 (English) miles per second. As, however, several groups of stars (like those in Orion and Ursa Major) have a common motion both in and across the line of sight, and are thus shown to be physically connected, the above method gives these stars an undue weight, and another reduction, in which each group is considered as a single star, places the apex of the Sun's way in R. A. 159°.7 ± 20°.2, Dec. + 50°.0 ± 14°.3, and gives for the velocity of motion 8.1 ± 2.0 miles.

Professor Vogel regards the observations as insufficient in number for determining the direction of motion with anything like certainty, but thinks that they furnish a more satisfactory value of the velocity than that deduced from proper motions with certain assumptions in regard to the distances of the stars. Assuming Struve's result for the direction of the Sun's motion, viz., R. A. 266°.7, Dec. + 31°.0, the velocity deduced from the Potsdam observations is 7.6 ± 1.8 miles.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR JULY AND AUGUST.

These two months being the most delightful of the year for astronomical work, we hope that our readers will not fail to make use of their opportunities to study the face of the sky. Nearly all of the planets will be visible under more or less favorable circumstances during some part of the night. The richest and most brilliant parts of the galaxy will be visible in the early evening.

At 9 o'clock, July 1, the constellation Leo will be low in the west. Below this, very near the horizon will be found the three planets Mercury, Venus and Mars. Higher up will be Virgo with the golden Saturn in the center of the constellation; north of Virgo, the great cluster Coma Berenices, and Bootes with the ruddy first magnitude star Arcturus; near the meridian to the south, Libra with the little green planet Uranus at its western boundary, ruddy Antares and the numerous claws of Scorpio, the crooked Serpens and Ophiuchus the serpent bearer; overhead the Northern Crown, *Corona Borealis*, and Hercules, containing the Apex of the Solar Way. Towards the east the great arch of the Milky Way extends from south to north with the constellations Sagittarius, Scutum Sobieski, Aquila, Cygnus and Lyra. In the morning one may see the constellations Capricorn, Aquarius, Pegasus, Cetus, Pisces, Aries, Andromeda, Perseus and Cassiopeia. All of these constellations contain interesting objects which we have not space to mention here but which are described in most hand books of astronomy. They may be well seen with telescopes of small aperture, from 3 to 5 inches, and even an ordinary opera-glass will reveal many wonderful features of the celestial dome, which may not be so well shown with more powerful instruments.

Mercury will be at greatest elongation east from the Sun, 26° 30′, July 11, and will therefore be visible to the naked eye, just after sunset, for several evenings about that time. Mercury will then be about 3° south and 2° east of Venus and Mars. Mercury will be at inferior conjunction August 8 and at greatest elongation west from the Sun, 18° 16′, August 25, when he will be visible in the morning.

Venus will be the bright "evening star" during these months, accompanied during the first days by Mercury and Mars and later by Saturn. On July 9 at $8^h\ 02^m$ A. M. central time Venus will be in conjunction with Mars at an apparent distance of only 18′ north. On that evening and on the preceding the two planets

may be seen together in the low power fields of small telescopes. It will be interesting to compare their apparent sizes and the color and brilliancy of their disks.

Venus will be in conjunction with the Moon July 14 at $3^h\ 42^m$ P. M., 3° 24′ south, and again Aug. 13 at 5^h P. M. 1° 41′ south. Toward the end of the month she will approach quite near to Saturn. The disk of Venus will during these months be almost fully illuminated, the gibbous phase becoming somewhat noticeable toward the end of August.

Mars will be low in the west after sunset and, during the first part of July, in the vicinity of Venus and Mercury as described in the preceding paragraphs. He is not favorably situated for observation. His apparent diameter is now less than 4″.

Jupiter will be in good position for morning observations. He is over 18° north of the equator so that he crosses the meridian at a high altitude. We may therefore expect that the results of observations of Jupiter's surface will be more valuable than those made during the past three or four years. Jupiter will be at quadrature, 90° west from the Sun, Aug. 22; in conjunction with the Moon July 9 at noon and again Aug. 5 at $2^h\ 13^m$ A. M.

Saturn will be "evening planet" with Venus and Mercury. He has passed the favorable position for this year but the rings may still be seen during July and August. He will be in conjunction with the Moon, a little over a degree north, July 18 at $7^h\ 36^m$ P. M. and Aug. 15 at 9^h A. M.

Uranus is also "evening planet" but considerably farther east than Saturn. During July he will be almost stationary, about 1° east and 30′ south of the fifth magnitude star λ Virginis. The two, planet and star, are not greatly different in brightness, but the former may be distinguished by the dull green color of his light if not by the clearly defined disk.

Neptune may be observed in the morning. He may be found about 6° northeast of Aldebaran, between the fifth magnitude stars τ and ι Tauri, 2° west and 30′ north of the last. The best way to find him will be to make a chart of all the stars visible in the space between τ and ι Tauri on several nights and see which star moves. Neptune during July and August will move about a degree and a half or three times the Moon's diameter eastward.

MERCURY.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
July 5.....	8 49.0	+ 18 23	6 34 A. M.	1 52.9 P. M.	9 12 P. M.
15.....	9 26.7	+ 13 42	6 52 "	1 50.2 "	8 48 "
25.....	9 37.0	+ 10 27	6 38 "	1 22.1 "	8 06 "
Aug. 5.....	9 16.2	+ 10 44	5 33 "	12 18.1 "	7 03 "
15.....	8 52.1	+ 14 05	4 15 "	11 14.7 A. M.	6 14 "
25.....	9 06.9	+ 16 02	3 42 "	10 50.2 "	5 58 "

VENUS.

July 5.....	8 15.4	+ 21 16	5 47 A. M.	1 19.3 P. M.	8 52 P. M.
15.....	9 05.8	+ 18 15	6 12 "	1 30.3 "	8 48 "
25.....	9 54.1	+ 14 25	6 38 "	1 39.1 "	8 40 "
Aug. 5.....	10 45.0	+ 9 28	7 07 "	1 46.7 "	8 27 "
15.....	11 29.8	+ 4 32	7 32 "	1 52.0 "	8 12 "
25.....	12 13.7	− 0 36	7 56 "	1 56.5 "	7 57 "

MARS.

July 5.....	8 24.7	+ 20 31	6 00 A. M.	1 28.7 P. M.	8 57 P. M.
15.....	8 50.7	+ 18 55	5 54 "	1 15.3 "	8 36 "
25.....	9 16.2	+ 17 06	5 49 "	1 01.4 "	8 14 "
Aug. 5.....	9 43.7	+ 14 54	5 43 "	12 45.6 "	7 49 "
15.....	10 08.2	+ 12 42	5 37 "	12 30.6 "	7 24 "
25.....	10 32.3	+ 10 22	5 32 "	12 15.4 "	6 59 "

JUPITER.

July 5.....	3 23 4	+ 17 36	1 14 A. M.	8 29.0 A. M.	3 44 P. M.
15.....	3 31.0	+ 18 03	12 40 "	7 51.1 "	3 15 "
25.....	3 37.8	+ 18 26	12 06 "	7 24.6 "	2 44 "
Aug. 5.....	3 45.5	+ 18 50	11 24 P. M.	6 44 5 "	2 06 "
15.....	3 50.6	+ 19 04	10 48 "	6 10.0 "	1 32 "
25.....	3 54.2	+ 19 15	10 12 "	5 34.5 "	12 57 "

SATURN.

July	5	12	28.3	−	0	25	11	31	A. M.	5	31.6	P. M.	11	32	P. M.
	15	12	30.2	−	0	39	10	54	"	4	54.1	"	10	54	"
	25	12	32.6	−	0	58	10	19	"	4	17.2	"	10	16	"
Aug.	5	12	35.8	−	1	19	9	40	"	3	37.1	"	9	34	"
	15	12	39.1	−	1	43	9	05	"	3	01.1	"	8	57	"
	25	12	42.8	−	2	07	8	31	"	2	25.5	"	8	20	"

URANUS.

July	5	14	17.9	−	13	20	2	12	P. M.	7	20.8	P. M.	12	30	A. M
	15	14	17.8	−	13	20	1	33	"	6	41.4	"	11	50	P. M
	25	14	18.0	−	13	21	12	54	"	6	02.4	"	11	11	"
Aug.	5	14	18.6	−	13	25	12	11	"	5	19.7	"	10	28	"
	15	14	19.4	−	13	29	11	34	A. M.	4	41.5	"	9	50	"
	25	14	20.8	−	13	36	10	56	"	4	03.2	"	9	11	"

NEPTUNE.

Date. 1893.	R. A. h	m	Decl. °	′	Rises. h	m		Transits. h	m		Sets. h	m	
July 5	4	43.8	+ 20	48	2	18	A. M.	9	48.4	A. M.	5	18	P. M.
15	4	45.2	+ 20	50	1	36	"	9	06.5	"	4	37	"
25	4	46.2	+ 20	52	1	02	"	8	32.3	"	4	03	"
Aug. 5	4	47.4	+ 20	54	12	20	"	7	50.1	"	3	21	"
15	4	48.2	+ 20	55	11	41	P. M.	7	11.7	"	2	42	"
25	4	48.9	+ 20	55	11	02	"	6	32.8	"	2	04	"

THE SUN.

July	5	7	00.2	+ 22	44	4	23	A. M.	12	04.4	P. M.	7	46	P. M.
	15	7	41.0	+ 21	26	4	31	"	12	05.8	"	7	40	"
	25	8	21.0	+ 19	31	4	41	"	12	06.3	"	7	32	"
Aug.	5	9	03.8	+ 16	47	4	53	"	12	05 7	"	7	18	"
	15	9	41.7	+ 13	50	5	05	"	12	04.2	"	7	04	"
	25	10	18.7	+ 10	31	5	16	"	12	01.8	"	6	47	"

Mr. Marth's Ephemerides of the Satellites of Saturn.

[From *Monthly Notices*, Jan. 1893.].

In this table the times have been changed from Greenwich Mean Time to Central Standard Time. The abreviations *Rh.*, *Te.*, *Di.*, *En.*, and *Mi.* stand for the names of the satellites Rhea, Tethys, Dione, Enceladus and Mimas. The letters *a*, *b*, *c*, *d*, and *e*, stand for conjunctions of the satellites in order as follows: With the preceding end of the outer ring; with preceding end of planet's equatorial diameter; with center of planet; with following end of planet's diameter; with following end of ring. The letters *n* and *s* signify that the satellite at the time of conjunction is north or south of the point designated by the preceding letter: *Sh.* means that the shadow of a satellite is near the central meridian of the planet; *Ecl. D.* and *Ecl. R.*, the disappearance and reappearance of a satellite at beginning and end of an eclipse. The letters e and w standing alone signify eastern and western elongations.

June 1893.			June 1893.			June 1893.			June 1893.		
16	2.4 pm	Rh sup		11.0 pm	Te an		5.6 pm	Te an		6.5 pm	Te bs
	2.7	Di e		11.2	Di ds		6.1	Mi as		7.5	Di bn
	4.3	Rh dn	20	1.5	En as		7.6	Te bn		8.5	Te as
	4.5	Mi en		4.4	Mi es		10.5	Te dn	27	1.5	Di e
	6.9	Rh en		5.3	Di w	24	12.2	Rh w		2.2	Te bn
	8.9	En an		9.6	Te es		4.1	En as		5.0	Rh es
17	1.3	En es		10.3	Mi as		4.3	Te es		5.1	Te dn
	3.1	Mi en		10.3	Rh an		4.8	Mi as		7.1	Te en
	5.5	Rh e	21	1.5	Di en		6.3	Te ds		7.6	Rh ds
	7.7	En as		3.0	Mi es		7.8	Di e		9.5	Rh inf
	8.5	Mi es		4.0	En es		9.2	Te bs	28	3.8	Te bs
	11.6	Di w		8.3	Te an	25	1.3	Rh bn		5.8	Te as
18	2.3	Di bn		8.9	Mi as		1.9	Di bs		10.4	Di w
	4.1	Rh es		10.3	Te bn		2.9	Te an	29	1.2	Di bn
	5.6	di dn		10.4	En as		3.3	Rh sup		2.5	Te dn
	6.1	Mi es	22	2.7	Di es		4.1	Di as		4.4	Di dn
	6.7	Rh ds		2.8	En en		4.9	Te bn		4.5	Te en
	7.8	Di en		4.9	Di ds		5.2	Rh dn		6.6	Di en
	8.6	Rh inf		6.9	Te es		7.7	Rh en	30	1.1	Te bs
	10.2	En es		7.5	Mi as		7.8	Te dn		3.1	Te as
	10.5	Rh bs		8.2	Di bs		9.8	Te en		7.8	Di es
19	2.7	En an		8.9	Te ds	26	1.6	Te es		10.0	Di ds
	5.7	Mi es		10.4	Di as		3.6	Te ds	July 1893.		
	9.0	Di es	23	1.5	Rh as		5.2	Di an	4	4.2	Rh sup
	9.0	Di es		5.4	En an		6.4	Rh e			

Configuration of Jupiter's Satellites at Midnight Central Time.

July										
1		3	2	1	○	4				
2			3	○	1	2	4			
3		3	1	○	2	4				
4		♌	2	○	4	3				
5		4	2	○	1	3				
6		4	1	○	2	3				
7		4	2	○	3	1				
8	4	2	3	1	○					
9		4	3	○	2	1				
10	4	3	1	○	2					
11		4	2	○	1	●				
12		4	2	○	3	●				
13			1	○	4	2	3			
14			♌	○	1	3	4			
15		2	3	1	○	4				
16			3	○	2	1	4			
17		3	1	○	2	4				
18		2	3	○	1	4				
19		2	1	○	3	4				
20			♌	○	2	4	3			
21				○	4	2	1	3		

July										
22	2	4	1	3	○					
23		4	3	○	2	1				
24	4	3	1	○	2					
25	4	2	3	○	1					
26	4	2	1	○	3					
27			4	○	1	2	3			
28			4	○	1	2	3			
29	2	4	1	3	○					
30			3	○	4	1	●			
31		3	1	○	2	4				
Aug.										
1		3	2	○	1	4				
2		2	1	○	3	4				
3				○	1	2	3	4		
4			1	○	2	3	4			
5		2	1	○	3	4				
6		3	2	○	1	4				
7	♌	3	1	○	2					
8	♌	4	3	○	1					
9	4	2	1	○	4					
10			4	○	2	1	3			

Aug.										
11			4	1	○	2	3			
12		♌	4	2	○	3				
13		4	3	2	○	1				
14		3	4	1	○	2				
15			3	4	○	2	1			
16			2	1	○	3	4			
17					○	2	1	3	4	
18				1	○	2	3	4		
19				2	○	3	4	1		
20			3	2	○	4	●			
21			3	1	○	2	4			
22				3	○	2	1	4		
23			2	1	○	4	●			
24				4	○	1	3	●		
25			4	1	○	2	3			
26			4	2	○	1	3			
27	4	2	3	1	○					
28		4	3	1	○	2				
29			4	3	○	1	2			
30	4	2	1	3	○					
31			4	2	○	1	3			

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A.....0h 52m 32s
Decl.....+81° 17′
Period.....2*d* 11h 50m
1893.

July	2	1 A. M.
	7	1 "
	11	midn.
	16	"
	21	"
	26	11 P. M.
	31	11 "
Aug.	5	11 "
	10	10 "
	15	10 "
	20	10 "
	25	9 "
	30	9 "

ALGOL.

R. A.....3h 1m 1s
Decl.....+ 40° 32′
Period.....2*d* 20h 49m

July	11	5 A. M.
	14	2 "
Aug.	3	3 "
	5	midn.
	23	5 A. M.
	26	2 "
	28	11 P. M.

λ TAURI.

R. A..... ....3h 54m 35s
Decl.....+ 12° 11′
Period.....3*d* 22h 52m

July	31	4 A. M.
Aug.	4	3 "
	8	2 "
	12	1 "
	15	midn.

δ LIBRÆ.

R. A.....14h 55m 06s
Decl..... .....— 8° 05′
Period..... ..2*d* 7h 51m

July	2	4 A. M.
	6	8 P. M.
	9	4 A. M.
	13	8 P. M.
	16	3 A. M.
	20	7 P. M.
	23	3 A. M.
	27	7 P. M.
	30	3 A. M.
Aug.	6	2 "
	13	2 "
	20	1 "
	27	1 "

U CORONÆ.

R. A.....15h 13m 43s
Decl.....+ 32° 03′
Period.....2*d* 10h 51m

July	1	11 P. M.
	8	9 "
Aug.	1	midn.
	8	10 P. M.
	15	8 "

U OPHIUCHI.

R. A.. .....17h 10m 56s
Decl.....+ 1° 20′
Period..... ....0*d* 20h 08m

July	5	midn.
	6	8 P. M.
	10	midn.
	11	9 P. M.
	16	2 A. M.
	16	10 P. M.
	21	2 A. M.
	21	11 P. M.
	27	1 A. M.

U OPHIUCHI Cont.

	27	9 P. M.
	31	midn.
Aug.	1	8 P. M.
	6	1 A. M.
	6	9 P. M.
	11	2 A. M.
	11	10 P. M.
	16	2 A. M.
	16	10 P. M.
	21	3 A. M.
	21	11 P. M.
	22	7 P. M.
	26	midn.
	27	8 P. M.

γ CYGNI

R. A.....20h 47m 40s
Decl.....+ 34° 15′
Period.....1*d* 11h 57m

July	1	5 A. M.
	4	5 "
	7	5 "
	10	5 "
	13	5 "
	16	4 "
	19	4 "
	22	4 "
	25	4 "
	28	4 "
	31	4 "
Aug.	3	4 "
	6	4 "
	9	4 "
	12	4 "
	15	4 "
	18	4 "
	21	3 "
	24	3 "
	27	3 "
	30	3 "

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
July 6	B.A.C. 410	6.0	13 16	54	14 17	240	1 01
8	54 Arietis	6.3	12 38	62	13 34	241	0 56
23	α Scorpii	1.4	8 28	166	9 19	232	0 51
24	43 Ophiuchi	5.8	8 38	79	10 07	300	1 29
Aug. 2	e Piscium	5.5	11 55	97	12 44	192	0 49
3	B.A.C. 609	6.0	12 45	33	13 44	259	0 59
4	π Arietis	5.7	11 13	35	11 58	271	0 45
4	ρ^2 Arietis	6.0	14 20	32	15 20	262	1 00
4	ρ^3 Arietis	6.0	14 24	110	15 05	184	0 41
5	B.A.C. 1189	6.0	12 31	97	14 16	214	1 45
16	86 Virginis	5.9	6 58	112	8 12	306	1 14
23	ω Sagittarii	5.1	13 39	10	14 15	305	0 36
25	38 Capricorni	6.9	8 40	100	9 48	208	1 08
25	37 Capricorni	6.0	8 42	63	10 06	245	1 24
25	$\varkappa$ Capricorni	5.0	14 30	47	15 35	248	1 05
27	φ^1 Aquarii	4.1	10 01	102	10 54	186	0 53
28	27 Piscium	5.1	7 02	107	7 43	198	0 41
28	29 Piscium	5.0	8 40	82	9 40	213	1 00
28	B.A.C. 8351	8.0	9 02	39	10 05	255	1 03
31	36 Arietis	6.5	15 53	38	17 08	257	1 15

Phenomena of Jupiter's Satellites.

		h	m				h	m			
July	4	2	35 A. M.	I	Ec. Dis.		9 12	22	"	II	Tr. Eg.
	5	12	54 "	I	Tr. In.		12 1	01	"	I	Ec. Dis.
		2	02 P. M.	I	Sh. Eg.		11	40 P. M.		I	Tr. In.
		3	06 "	I	Tr. Eg.		13 12	30 A. M.		I	Sh. Eg.
	6	1	23 A. M.	II	Ec. Dis.		1	12 "		III	Sh. In.
	12	1	17 "	III	Oc. Re.		1	52 "		I	Tr. Eg.
		1	45 "	I	Sh. In.		2	55 "		III	Sh. Eg.
		2	53 "	I	Tr. In.		14 3	46 "		II	Ec. Dis.
	13	2	16 "	I	Oc. Re.		16 12	14 "		II	Sh. Eg.
	15	12	38 "	II	Sh. Eg.		12	41 "		II	Tr. In.
		12	41 "	II	Tr. In.		2	58 "		II	Tr. Eg.
		3	00 "	II	Tr. Eg.		19 2	55 "		I	Ec. Dis.
	19	12	33 "	III	Ec. Re.		20 12	12 "		I	Sh. In
	20	12	51 "	I	Ec. Dis.		1	35 "		I	Tr. In.
	21	1	32 "	I	Tr. Eg.		2	24 "		I	Sh. Eg.
	22	12	51 "	II	Sh. In.		3	47 "		I	Tr. Eg.
		3	12 "	II	Sh. Eg.		21 12	55 "		I	Oc. Re.
		3	23 "	II	Tr. Eg.		10	15 P. M.		I	Tr. Eg.
	24	12	46 "	II	Oc. Re.		23 12	29 A. M.		II	Sh. In.
	26	3	05 "	III	Ec. Dis.		2	49 "		II	Sh. Eg.
	27	2	45 "	I	Ec. Dis.		3	17 "		II	Tr. In.
	28	1	19 "	I	Tr. In.		24 12	42 "		III	Oc. Dis.
		2	14 "	I	Sh. Eg.		2	08 "		III	Oc. Re.
	29	12	40 "	I	Oc. Re.		9	54 P. M.		II	Ec. Re.
		3	26 "	II	Sh. In.		10	25 "		II	Oc. Dis.
	31	12	47 "	II	Ec. Re.		25 12	42 A. M.		II	Oc. Re.
		1	10 "	II	Oc. Dis.		27 2	06 "		I	Sh. In.
Aug.	4	1	56 A. M.	I	Sh. In.		3	29 "		I	Tr. In.
		3	16 "	I	Tr. In.		11	17 P. M.		I	Ec. Dis.
	5	2	37 "	I	Oc. Re.		28 2	49 A. M.		I	Oc. Re.
		10	30 P. M.	I	Sh. Eg.		9	57 P. M.		I	Tr. In.
		10	55 "	III	Sh. Eg.		10	47 "		I	Sh. Eg.
		11	57 "	I	Tr. Eg.		29 12	08 A. M.		I	Tr. Eg.
	6	2	42 A. M.	III	Tr. In.		30 3	04 "		II	Sh. In.
	7	1	09 "	II	Ec. Dis.		11	06 P. M.		III	Ec. Dis.
		3	24 "	II	Ec. Re.		31 12	34 A. M.		III	Ec. Re.
		3	51 "	II	Oc. Dis.		10	15 P. M.		II	Ec. Dis.

XUM

Phases and Aspects of the Moon.

	d	h	m	
Last Quarter	July 6	4	06	P. M.
Perigee	" 11	5	30	"
New Moon	" 13	6	47	A. M.
First Quarter	" 20	11	02	"
Apogee	" 23	8	12	P. M.
Full Moon	" 28	2	10	"
Last Quarter	Aug. 4	10	23	"
Perigee	" 8	3	42	"
New Moon	" 11	2	48	"
First Quarter	" 19	3	52	A. M.
Apogee	" 20	1	00	P. M.
Full Moon	" 27	2	43	A. M.

Ephemeris of Comet 1892 VI (Brooks Aug. 28).

(from *Astr. Nach.* No. 3162).

Berlin Midn.		R. A.			Decl.			log *r*	log Δ	Br.
		h								
June	9	17	37	06	− 24	43.2		0.4236	0.2148	1.21
	13		31	46	24	08.2		0.4313	0.2262	1.11
	17		26	45	23	34.3		0.4389	0.2387	1.01
	21		22	07	23	01.8		0.4462	0.2520	0.92
	25		17	53	22	31.1		0.4535	0.2658	0.84
	29		14	07	22	01.7		0.4606	0.2805	0.76
July	3		10	46	21	34.5		0.4675	0.2954	0.68
	7		07	52	21	09.6		0.4743	0.3107	0.62
	11		05	26	20	46.5		0.4810	0.3264	0.56
	15		03	26	20	25.6		0.4875	0.3421	0.50
	19		01	52	20	06.6		0.4939	0.3580	0.45
	23	17	00	44	19	49.6		0.5002	0.3739	0.41
	27	16	59	58	19	34.5		0.5064	0.3897	0.37
	31		59	35	19	21.0		0.5125	0.4055	0.33
Aug.	4		59	33	19	09.4		0.5185	0.4210	0.30
	8	16	59	50	18	58.9		0.5243	0.4364	0.27
	12	17	00	27	− 18	50.1		0.5301	0.4515	0.25

Ephemeris of Comet 1893 I (Brooks 1892 Nov. 19).

(from *Astr. Nachr.* 3162).

Berlin Midn.		R. A.			Decl.			log *r*	log Δ	Br.
June	9	1	35	34	+ 11	03.7		0.3996	0.4749	0.101
	13		35	41	10	34.8		0.4073	0.4714	0.099
	17		35	33	10	04.1		0.4148	0.4673	0.098
	21		35	07	9	31.0		0.4221	0.4629	0.097
	25		34	22	8	55.6		0.4293	0.4580	0.096
	29		33	19	8	17.5		0.4364	0.4528	0.095
July	3		31	55	7	36.5		0.4434	0.4474	0.094
	7		30	09	6	54.4		0.4502	0.4417	0.094
	11		28	01	6	05.1		0.4569	0.4358	0.093
	15		25	29	5	14.4		0.4635	0.4299	0.093
	19		22	31	4	20.2		0.4700	0.4240	0.093
	23		19	08	3	22.2		0.4764	0.4183	0.092
	27		15	18	2	20.7		0.4826	0.4127	0.092
	31		11	02	1	15.6		0.4888	0.4076	0.092
Aug.	4		06	19	+ 0	07.1		0.4949	0.4029	0.091
	8	1	01	10	− 1	04.6		0.5008	0.3988	0.090
	12	0	55	31	− 2	19.3		0.5067	0.3955	0.089

Reappearance of Finlay's Periodic Comet.—Mr. Finlay at the Cape of Good Hope rediscovered on May 17 the comet which was originally discovered by him in 1886. The position of the comet as determined May 18.6262 was R. A. 23^h 47^m 31^s.2; Decl. − 5° 01′ 50″, which agrees, within + 7^m in R. A. and + 12′ in Decl., with the ephemeris calculated by Schulhof, published in our April and May numbers. The comet is described as circular, 1′ in diameter, 11 magnitude, very diffuse, with no tail.

NEWS AND NOTES.

Our readers will please remember that this publication will not appear in July. Next issue will be for August.

Astronomical Spectroscopy is to be the name of the translation of Dr. Scheiner's Spectral-Analyse der Gestirne, now being made by Professor Frost. The book will appear about Nov. 1, 1893, and its price will be five dollars.

E. E. Barnard's European Visit.—On the morning of May 20, E. E. Barnard and wife sailed from New York for Liverpool on the Aurania, Cunard line. Mr. Barnard has been granted a year's vacation from Lick Observatory, and it is his plan to visit the Observatories of England, Scotland, Ireland, France and Germany. We know he will meet everywhere, on the other side of the water, a most hearty welcome, for there is not an astronomer in foreign lands who does not know of him by reputation, young as he is, and the cordial greeting in store for him from scientists there will be a deserved recognition of merit which he has nobly earned in the science he so ardently loves and has already so signally honored. He promises to remember us with communications in his absence.

Astronomy Popularized in America.—There seems to be no doubt that the interest taken in astronomy in America is rapidly on the increase, and the demand for large telescopes there have played no small part in helping to stir up in many minds the desire for enlightenment in this fascinating science. Increase in the number of students and amateurs, and rapidly growing demands for small telescopes are signs that can not be misconstrued, indicating as they do the vast interest that even to-day is shown in the oldest of sciences. To satisfy and further these favorable omens, or, in other words, to bring those who can instruct into closer relations with those who are to be instructed, the editors of ASTRONOMY AND ASTRO-PHYSICS propose, assuming they get a sufficient number of subscribers, to issue a publication entitled "Popular Astronomy." The idea of this project is that it should serve as a guide for self-instruction, and supply a medium for queries and answers for methods of work, facts, books, etc. They propose to commence with a series of topics for observation, the stars, moon, planets, etc., assuming that the readers are supplied only with an opera glass or small telescope. It is to be in no sense professional "except to be accurate in statement of fact and principle without being technical in terms." The first number can be ready by September of this year if the subscribers are forthcoming.—*Nature* (England.) May 4, 1893.

Photometric Observations of the Brightness of the Asteroids.—The Harvard College Observatory will soon publish Henry M. Parkhurst's Photometric Observations of Asteroids and Variable Stars. This valuable work will consist of 105 pages of observations and tables of reduction, and will give the results of ten years' observations made by Mr. Parkhurst at his home in Brooklyn, N. Y., with a 9-inch Fitz refractor. The light of 36 of the asteroids, ranging from the 6th to the 13th magnitudes, has repeatedly been observed by him during the above period.

In the earlier observations Mr. Parkhurst thought there was evidence, in one or two cases, of a variation of the light of an asteroid which might be due to axial rotation and it was hoped that the rotation of these little bodies might

thus be detected. His more extended work, however, does not verify this, as none of the asteroids show any such discordances in the more refined observations. None of them have shown any variation in their light and their rotations cannot therefore be photometrically determined. The observations are made by the method of light extinction: the image of the object being observed to disappear through a medium of gradually increasing density, a photometric wedge. Standard comparison stars were observed at the same time, and every precaution taken to eliminate all errors of observation. The observed magnitude of the asteroid is corrected for deficient illumination, for phase, etc., being reduced to distance unity from the Earth and the Sun. Observations of the same asteroids extending over many years and thus reduced to a constant distance, are strikingly accordant.

As these observations extend over some ten years they also show that there has been no variation in the brightness of the Sun during that time amounting to as much as one per cent, or it would have been detected in the work. Mr. Parkhurst finds also that all sides of the Sun give out essentially the same amount of light.

He finds that the light of the asteroids is far more constant than that of the stars. According to his observations an asteroid is twice more reliable, as a constant of comparison, than any fixed star. As early as 1860 he had come to the conclusion that every star in the sky was more or less variable, and this seems to be verified by his observations. This therefore makes the asteroids the most reliable constants for light comparison. But this one important value of these little bodies cannot now be utilized, as the ephemerides of most of them have been discontinued.

The Yerkes' Telescope.—The following facts about the 40-inch Chicago telescope have been obtained from Messrs. Warner & Swasey who are building the great tube pier and clock-work.

The pier or column is made in five sections. The base section weighs about 18 tons, the other sections weighing about 5½ tons each. The height of the column, from base to top is 31 feet 4 inches. Each section of the pier is above 6½ feet high.

The head of the pier is of cast iron, in one piece and weighs 5½ tons. The total weight of the pier and head is about 45 tons. The height from the base of the pier to the center of motion is 43 feet 6 inches.

The polar axis is made of steel 15 inches in diameter, 13 feet long and weighs about 3½ tons. The declination axis is made of steel 12 inches in diameter and weighs about 1¾ tons.

The tube is of sheet steel and its total length 62½ feet exclusive of eye-end. The largest diameter in the center, is 52 inches. It is 28 inches in diameter at eye end, and 43 inches at object-glass end. The complete tube will weigh about 6 tons. The focal length of the objective is to be about 64 feet

The clock will weigh about 1½ tons and is wound either by hand or by electric motor.

All quick or slow motion and clamps for right ascension and declination are operated by hand and electricity, from floor, from eye-end and from balcony.

The total weight of the telescope will be about 75 tons.

To give an idea of the immense size of this instrument when the telescope is pointed to the zenith the object-glass will be 72 feet up in the air, or about as high as a seven story house.

It is to have an elevating floor like that of the Lick Observatory.

In the *Comptes Rendus* for March 27th and April 4th of this year Mr. Loewy, of the Paris Observatory has two important articles. In them he discusses the zero-points of the photographic catalogue plate whose centre is at $10^h 52^m + 23°$ and shows that the best results are obtained by connecting it with the four plates which have a corner at its centre. Without these connections the positions of the stars on the central plate would be less accurate than the photographic method demands; and we may say that with them the accuracy attained (a probable error of about $\pm$ 0″.15 in both co-ordinates combined, at the very centre more near the edges) could be readily improved by new observations of the same stars. Taking into account all previous available catalogues the probable error of each star's place does not amount to less than $\pm$ 0″.5 in either co-ordinate. As it is now perfectly easy to make this as small as $\pm$ 0″.2 by four observations of each star, we see that a considerable diminution of the p. e. of the zero points is possible. Fortunately the many meridian observations which this increase in accuracy requires can be deferred for the present; and I suggest that American meridian observers who have the instruments and time necessary shall investigate, during the next few years, the question of the accuracy attainable, for stars of various magnitudes and in various parts of the heavens, by a combination of old and new observations, making such as are necessary. Studies of this kind are entirely essential if the waste of labor, which has always been a feature of meridian observations in most places, shall be prevented for the future.

My own project of observing the positions of all standard polars, and combining with them the results of previous observations fits very well into this scheme of operations; but of this more bye-and-bye. T. H. SAFFORD

Mr. Parkhurst's Discovery of Donati's Comet—It was June 2d, 1858 that Donati discovered at Florence, the comet which has made his name famous. It was then a very faint telescopic object, and not until the latter part of August did it begin to attain that naked eye visibility which has made it classical.

Before Donati's discovery was known in America, Mr. Parkhurst accidentally discovered it on June 29th, while sweeping for Comet IV, 1858. He was searching for Comet IV with a 6-inch refracting telescope and found in the proper position a faint tailless comet which he assumed was the one which he was in search of. Observations soon showed, however, that the object must be a new comet as its motion was at right angles to that of IV. He did not learn for some time that he had been anticipated by another, in finding one of the most splendid comets on record. Looking at Mr. Parkhurst with his long white hair and beard and with his gentle face one can not repress the wish that he had not been anticipated in the discovery of this beautiful comet.

Mr. Parkhurst still has the six-inch telescope with which he found Donati's comet. The tube is unmounted and stands in a corner of his Observatory. It is not known who made the glass, which was so poor in definition that it was refigured by the elder Fitz.

The Lick Telescope Disturbed by Wind. Refering to the note by Professor Holden in the May number of this journal, on the matter of protecting the large telescope from the wind, I desire to say that I suggested the plan of cutting off the wind from the instrument by closing the lower half of the slit with canvas, soon after I commenced to work with the 36-inch. Most of my work with the micrometer, except on stars very far south, was done with the objects at an altitude of not less than 40°, and if the vibration of the telescope due to the wind coming through this part of the opening could be avoided, the remaining effect would be

comparatively unimportant. The loss of time due to this disturbance was no trifling matter. It is impossible to do any good work with the micrometer while the telescope is shaking. The only thing to do was to turn the dome in some other direction; and frequently in a high wind, even when the shutter was in an opposite quarter, the disturbance of the instrument was very annoying. In some of the work done there, with the spectrograph for instance, this vibration was of no serious consequence. I never lost faith in the practical value of the device suggested, and never saw the time during my stay at Mt. Hamilton when I did not wish to do more double star work than I did, or could do under the circumstances. Certainly Professor Holden in saying that finally I did not care to have this improvement made on my account is an error, and he has probaby confused me with some one else in repect to this matter. As a matter of fact I was not aware that the rods referred to had been attached, but as my work in the dome was entirely at night, they might have easily escaped my notice.

Chicago, May 20. S. W. BURNHAM.

Wind at the Lick Observatory. I was very much surprised in reading the note from the director of Lick Observatory in the May number concerning certain experiments that had been commenced at the Lick Observatory to provide means for reducing the effect of the wind upon the 36-inch telescope.

I had never heard of any such experiments and this is the first intimation that I ever had that such had ever been tried. I had never heard of the existence of the "rods," etc., which had been attached to the slit for the purpose of conducting such experiments.

It is to be regretted that these experiments were not reduced to practice, as it is entirely too important a matter to have been neglected.

I regret that my attention was not directed to the existence of these rods, etc., so that an effort on my part might have been made to test the efficiency of some kind of screen to close the lower part of the slit, and to protect the telescope from the wind. E. E. BARNARD.

New York, May 16, 1893.

Photographs of the Broadening of the Lines in Sun-spot Spectra.—Professor Young and his assistant, Mr. Reed, have been experimenting with isochromatic plates in photographing Sun-spot spectra with the 23-inch. They have secured some very satisfactory negatives which clearly show the unmistakable broadening of the Fraunhofer lines in the Sun-spot spectra. Their most successful results have been obtained in the red region of the spectrum.

The Last Observations of the 5th Satellite of Jupiter.—The last observations of this object that were obtained at the Lick Observatory with the 36-in. were on January 5th and 8th, 1893, at which times it was seen at western elongation and described as extremely faint. It was then closely following the ephemeris computed for it by Mr. Marth. Professor Young with the 23-inch at Princeton observed it last on December 30th 1892. He saw it at eastern elongation at 6 P. M. In the observations at Mt. Hamilton the planet was over two hours further west of the meridian than when observed at Princeton, which would in the main account for its greater faintness with the 36-inch.

Professor H. S. Prichett of Washington University, St. Louis is making a thorough discussion of the orbit of the satellite from which many interesting facts will be developed.

Some valuable observations were also obtained of it by Mr. Brown with the 26-in. at Washington before its removal. These observations have not yet been published.

The following are the results of the measures of the satellite made with the 36-in. at the Lick Observatory:

Distance from centre of Jupiter, (reduced to distance 5.20).

From measures at east elongation 48″.09 ± 0″.06 (14 nights).

From " " west " 47 .62 ± 0 .18 (7 nights).

These would correspond relatively to the following distances from the center of Jupiter:

When east of the planet 112500 ± 140 miles.
When west of the " 111410 ± 410 "
Thus indicating some excentricity to the orbit.

From the observations the periodic time is $11^h\ 57^m\ 23^s.1$ and the motion of the satellite in its orbit about 16.4 miles a second.

During the measures of the satellite the diameters of Jupiter were frequently measured. These observations were made through smoked mica and are as follows—the measures being reduced to distance 5.20.

Equatorial diameter 38".38 ± 0".03 (20 nights).
Polar diameter 36 .03 ± 0 .05 (14 nights).

These would correspond to the following

Equatorial diameter 89709 ± 65 miles.
Polar diameter 84300 ± 80 miles.

These values are in close accordance with the best filar micrometer measures of the diameters of Jupiter. Except the polar diameter, perhaps, which is somewhat greater than other determinations. Heliometer measures of the diameter of Jupiter are uniformly about 1" less than the values obtained with the micrometer.

The satellite is therefore about 67000 miles distant from the surface of Jupiter.

The angular hourly motion of the 5th satellite is about 30°.11. Though this is much smaller than that of Phobos, the inner satellite of Mars, yet the actual velocity in its orbit is some 12 times as great as that of Phobos.

Though the older satellites of Jupiter are readily expanded into small round discs with comparatively small telescopes, the new one has never appeared other than a point of light under the best conditions with the 36-inch. It has been impossible to detect a trace of its shadow when it should be in transit across Jupiter's disc. Until better material is at hand the satellite is assumed to be of the 13th magnitude and not far from 100 miles in diameter.

Removal of the Warner Observatory.—It has been for sometime the intention of Dr. Lewis Swift to remove his telescope from Rochester to a more favorable climate. The increase of electric lights and smoke from the city and the notorious cloudiness of Rochester, have all combined in late years to make observations of faint objects, such as Dr. Swift is interested in, all but impossible. The location for the rebuilding of this Observatory has at last been decided upon, and the instruments and library are already packed and the removal will begin immediately.

The Observatory is to be removed to the State University at Boulder, Colorado, and Dr. Lewis Swift and his son Edward are to become connected with the astronomical department of the University with suitable salaries.

As the 16-inch possesses a fine Clark filar micrometer, with Burnham's illumination, it might be suggested that the most important piece of work that could be undertaken just now with the instrument in its new position would be a careful series of micrometer measures of the 1,000 odd nebulæ discovered by Swift in the past ten years. This would be a very valuable contribution to astronomy and is a piece of work that might well be undertaken by the younger Swift.

Though the Observatory was the property of Mr. Warner, the 16-inch telescope is the personal property of Dr. Swift, being a present to him by the citizens of Rochester.

Proposed Change in Reckoning the Beginning of the Astronomical Day.—The Astronomical and Physical Society of Toronto, co-operating with the Canadian Institute, of Toronto, an older body already identified with reforms in Time Reckoning, is distributing to every astronomer, whose address can be obtained, a circular letter having for its object the obtaining of a consensus of opinion on the subject of the Sixth Resolution of the Washington International Conference of 1884, which was carried unanimously by the representatives of the twenty-five nations there assembled, counting among them several astronomers of world-wide fame. This resolution was as follows: "The Conference expresses the hope that, as soon as practicable, the Astronomical and Nautical Days will be arranged everywhere to begin at Mean Midnight." The circular letter is a pamphlet of twelve pages, and includes the report of a joint committee, of which Dr. Sandford Fleming, is Chairman, and the opinions, for and against the change, found in the writings of Sir John Herschell, M. Otto Struve, Mr. Christie, the Astronomer Royal, Professor Newcomb, the late Commodore Franklin, Mr. Charles

Carpmael, F. R. A. S., and Mr. Arthur Harvey, the last two being the Presidents of the societies issuing the circular. The report of the Joint Committee states that if any action is to be taken on the resolution, the most appropriate day for the new reckoning to take effect would be the first day of the new Century and that as the ephemerides are usually prepared four or five years in advance, a common understanding should not be delayed beyond 1895 or 1896, and suggests that answers be secured to the following question: "Is it desirable, all interests considered, that on and after the first day of January, 1901, the Astronomical Day should everywhere begin at Mean Midnight?" The two societies in Toronto have arranged to receive replies to this question and will, in the most impartial manner, collate them and cause them to be published in a report, a copy of which will be sent to every one who sends in an answer. It is presumed that this report will be a valuable one and one full of interest to scientific men the world over. Categorical replies will be received, but anyone, desiring to do so, may give reasons for his views. Great difficulty has been met with in procuring even a partial list of observers and others; in fact, some months' delay in issuing the circular has been caused by this. As it is, the Joint Committee is in possession of a list by no means full and complete. For this reason, many astronomers, chiefly amateurs whose opinions are very desirable, may not receive the circular; this must be regarded as accidental, not as intentional. Any scientific man who has a practical interest in the subject, may obtain a copy of the pamphlet if he send his name and address to Mr. G. E. Lumsden, corresponding secretary of the Astronomical Society, Toronto. It is to be hoped that this circular will be received and the question answered by everyone in the spirit which animates the societies issuing it. Those bodies only wish to serve the interests of science and, if the consensus of opinion be in its favor, to do something in moving the world to take advantage of that which, to them, appears to be the most opportune date for making the change suggested. Anyone wishing to send in an answer to the above question, may address it to The Joint Committee on Astronomical Time, Canadian Institute, Toronto, Canada.

Baltimore Astronomical Society.—The seventh regular meeting of the Baltimore Astronomical Society, section of the Maryland Academy of Sciences, was held May 9th. Mr. Gildersleeve in the chair. Mr. Pitts exhibited a model illustrating the stationary point and retrograde motion of planets in their orbits.

J. Stahn, Secretary of Society gave a lecture on Astronomy using lantern slides furnished by Mr. J. Patten, the stereopticon being provided by Mr. J. Pitts. Following the lecture some time was used in giving instruction in astronomy from Lockyer's text-book. Meetings of the society occur regularly on the 2nd Tuesday of each month.

The Astronomical and Physical Society of Toronto.—The meeting of this Society on the 18th of April, was held in the Physical Science Rooms of the University of Toronto in order that Mr. C. A. Chant, B. A., Lecturer on Physics, might read a paper, with experiments, on The Polarization of Light. There was a large attendance of members and of the general public. Mr. Chant was very successful and received the warm commendations of Mr. Charles Carpmael, F. R. A. S., President of the Society, Mr. John A. Paterson, M. A., Mr. A. Elvins and others. At the meeting on the 2nd of May, five active members were elected, the constitution of the Society was amended and consolidated; solar, planetary, stellar and other observations were reported; and it was announced that the Third Annual Report would appear in a few days. After routine, the meeting was addressed at some length and in a very interesting manner, by Dr. M. A. Veeder, of Lyons, N. Y., who had spent the day in town in consulting with Mr. Carpmael, Director of the Toronto Magnetic Observatory, whose records extend over a period of half a century. Dr. Veeder dwelt upon the expedition to northern-most Greenland, of Lieutenant Peary, U. S. N., who has consented to record observations of auroræ upon a plan that will enable comparisons to be made in detail with records from other localities. The doctor expressed himself as confident that these observations which will extend over two years, will go far to remove certain difficulties which now meet the investigator of auroræ. Dr. Veeder then took up the general subject of auroræ and, in reply to questions and otherwise, spoke of his hopes and plans. Members of the Society scattered throughout Ontario are assisting in making regular observations. Mr. G. G. Pursey read an interesting paper on Solar Heat.

PUBLISHER'S NOTICES.

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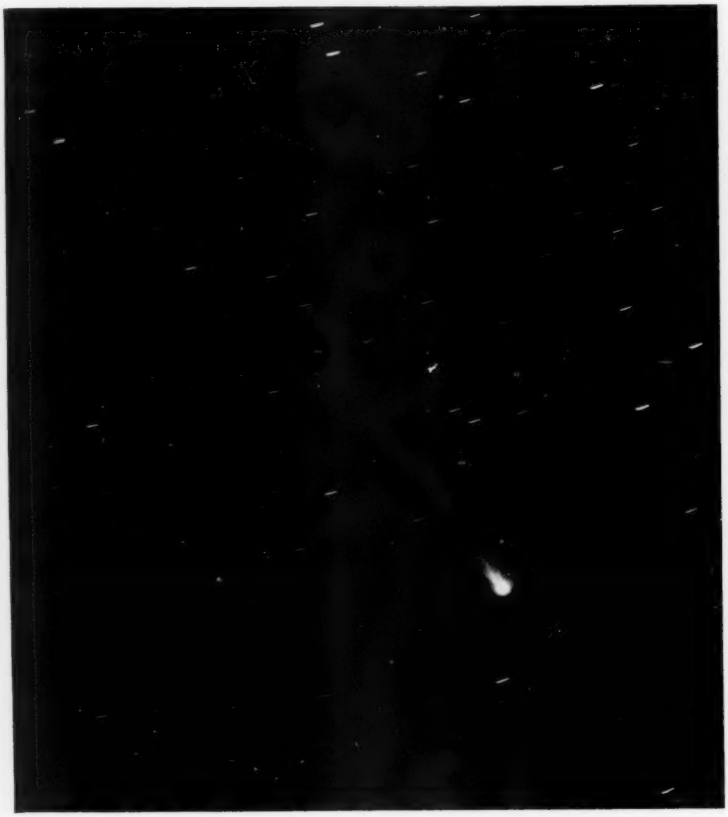

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